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A. C. TRUE, Director.

PROGRESS REPORT ON EXPERIMENTS IN SUPPLEMENTAL IRRIGATION WITH SMALL WATER SUPPLIES AT CHEYENNE AND NEWCASTLE, WYOMING, 1905–1908.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., October 20, 1909.

Sir: I have the honor to transmit herewith a progress report on experiments carried on at Cheyenne and Newcastle, Wyo., in irrigating small areas in connection with the farming of larger areas without irrigation. The greater part of the land lying between the one hundredth meridian on the east and the Rocky Mountains on the west is beyond the reach of canals from the streams of that section, and the water supply is not sufficient to irrigate any considerable part of it. Consequently the agriculture of this region must be principally such as can be carried on without irrigation. Notwithstanding previous failures to establish permanent homes there, these lands have been taken up very rapidly within the last few years, and the work reported in this circular was undertaken for the purpose of demonstrating to the incoming settlers the possibilities of developing a water supply for the irrigation of a small part of each landholding and the great advantages to be gained from its use. Although the years covered by this report have had precipitation far above the normal, irrigated crops have been far superior to crops grown without irrigation, and in addition the irrigated plats have yielded crops every season, while the unirrigated land has yielded crops no oftener than every other year, and those crops were usually light.

The meteorological records for the Great Plains show that the wet and dry years occur in cycles; and while irrigation is of value every year, its greatest value will be during a succession of dry years, when, but for irrigation, no crops will be grown. While this is a progress report, and the experiments reported have not been continued long enough to demonstrate fully the points covered, the results are such as to justify the belief that the general adoption of the plans suggested in this report will do much to prevent a recurrence of the disastrous failures which have marked previous attempts to settle this region. It is therefore recommended that this report be published as a circular of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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EXPERIMENTS IN SUPPLEMENTAL IRRIGATION.

INTRODUCTION.

Within the boundaries of approximately the one hundredth meridian on the east, the Rocky Mountains on the west, Canada on the north, and the Gulf of Mexico on the south lies an extensive area of fertile prairie land having an annual rainfall of 10 to 20 inches. This area embraces about 300,000,000 acres and is known as the semiarid belt. As yet it is practically unoccupied, and owing to a limited water supply can be but partially reclaimed by irrigation. Since the early eighties ambitious men have endeavored to push agricultural development far out over these rolling prairies, but years of drought following periods of success have caused bitter failure and a return to a more generous country.

Of recent years many systems for the utilization of these semiarid lands have been advocated. Some of them having been followed during years of normal rainfall have proven successful and so-called dry farming is now widely practiced. But years of drought may again occur, and it is only with the assurance of a small water supply that the farmer can fortify himself against a total failure, thus producing a few crops to tide over the unfruitful period to a year of plenty.

Of the several systems of soil culture adopted in dry farming probably summer tillage or fallowing is the most important. Summer tillage usually produces very good crops of annuals, such as wheat, oats, corn, and potatoes, in alternate years; but perennials, including trees, vines, small fruits, and alfalfa, which remain in the same ground year after year, require moisture continually not only to produce crops but to keep the plants from perishing. Usually these latter can not be grown successfully with summer fallowing, but require an artificial supply of water.

Small water supplies for irrigation may be of several kinds: Wells, with pumps and tanks; small storage reservoirs to catch storm waters coming down coulees, draws, and small stream beds; intercepting ditches across broad slopes directing the run-off to the orchards or fields below; and the use of the soil and subsoil to store the storm waters of spring freshets. The rains of the season may come at opportune times for general crops and no additional moisture will be necessary, but if in a continued dry spell the farmer has a small supply of water at his command it will mean to him the difference between success and failure.

Since the days of Abraham, in the evolution from the pastoral to the agricultural, wells of water have been one of the prime factors in the advancement of the human race. Without a bountiful supply of pure water, for domestic purposes at least, a home on the plains is a failure. There are extensive areas on the Great Plains where a water supply is unavailable, either on account of geological formations or the presence of a high percentage of alkali. Such tracts will either remain open grazing lands or will occasionally be farmed by cooperative methods with powerful machinery, the owners living in the nearest villages.

Hauling water in barrels 5 to 10 miles is resorted to sometimes, but water thus becomes a luxury and often both men and horses are denied their fill. Farming under such conditions becomes a burden and the farm will be abandoned sooner or later for something better.

At Cheyenne and Newcastle, Wyo., and Eads, Colo., the Office of Experiment Stations as a part of its irrigation investigations has established farms and built small reservoirs, installed power, both windmills and gasoline engines, and is demonstrating the value of having a small water supply as an auxiliary to the dry farm. Not only this, but the value of storing flood waters in the soil is being demonstrated also. On the south farm at Cheyenne each winter and spring the flow from Crow Creek is diverted through an open ditch to the various tracts, filling the soil with water to be held for the crops the following year, thereby insuring a successful season.

These farms have been maintained since 1905, and this circular contains an account of the work done at Cheyenne and Newcastle, Wyo., up to and including the season of 1908. These farms were under the supervision of F. C. Herrmann during the seasons of 1905 and 1906, of F. W. Roeding in 1907, and of O. W. Bryant in 1908 and 1909. John H. Gordon has had immediate charge of the work on the Cheyenne farm and R. E. Mahoney on the Newcastle farm. The portion of this report relating to water supply was furnished by P. E. Fuller, irrigation engineer, who has been in charge of that phase of the work. The soil-moisture determinations were made by H. T. Nowell, irrigation engineer, of the Wyoming Experiment Station.

Through the active interest of the Young Men's Literary Club and the Board of Trade of Cheyenne, Wyo., a cooperative fund was secured, the Chicago, Burlington and Quincy and the Union Pacific railway companies contributing liberally. A portion of the fund for the Newcastle station was advanced by the Wyoming Experiment Station at Laramie, while later the State of Wyoming set aside a small amount for the work at both farms. The balance of the expense has been met by the Office of Experiment Stations.

THE CHEYENNE FARM.

The Cheyenne experimental farm lies in section 4, township 13 north, range 66 west, and is about 1.75 miles east from the business center of the town. The farm consists of two separate tracts of 28 and 40 acres of cultivated land known as the north and south farms, respectively. Crow Creek, a tributary of the South Platte, passes between the two tracts in an easterly direction and, together with its bottom lands, covers an area about 80 rods broad. The tracts are located upon the so-called second bench, about 25 feet above the normal stream flow. Having an open subsoil, the farms have good underdrainage and are above the influence of the creek. The farm is in plain view from both the Union Pacific and the Chicago, Burlington and Quincy trains as they pass along its northern boundary. The high embankments of these railways divert the run-off from the nearby hills, so that the fields receive no water except from precipitation or irrigation.

SOIL.

The soil is not uniform, as shown by analyses, and contains much gravel. There is some clay present on the north farm, but sandy loam predominates. The subsoil of both tracts is open and does not hold moisture well, the water draining through to the creek below. With the exception of a small area on the north farm, which was cultivated one season more than twenty years ago, the sod had never been turned previous to 1905. Before the farm was planted to crops a soil examination was made by A. T. Sweet, of the Bureau of Soils, with the following results:

Chemical examination of soils on experiment farm and in vicinity of Cheyenne, Wyo.

EXPERIMENT FARM.

Depth.	Organic matter.	Calcium carbonate.	Parts per million water-soluble salts.	Place from which sample was taken.
Inches.	*Per cent.*	*Per cent.*		
0–10	1.5	None.	170	Center of north farm.
10–30	(a)	9.3	325	Do.
0–12	1.6	None.	185	Middle of east end of north farm.
0–18	.6	None.	155	20 feet from middle of south line of south farm.
18–30	2.1	5.0	380	Do.
0–20	1.3	None.	215	Center of south farm.
0–36	2.8	5.9	835	Creek bottom.

VICINITY OF CHEYENNE.

0–12	2.0	0.0	375	15 rods north of center sec. 36, T. 14 N., R. 67 W.
12–44	2.5	0.0	395	Do.
0–15	.6	4.4	420	80 rods west of center sec. 20, T. 14 N., R. 66 W.
15–39	(a)	15.2	490	Do.
39–72	(a)	9.1	2,335	Do.
0–10	1.7	0.0	140	Near middle of east side sec. 30, T. 14 N., R. 66 W.
10–37	.3	4.9	350	Do.
0–14	2.1	5.5	370	80 rods north and 60 rods west of SE. corner sec. 2, T. 13 N., R. 67 W.
14–42	(a)	11.6	4,650	Do.
0–72	.5	5.7	300	Near middle of north side, sec. 17, T. 13 N., R. 66 W.

a The small amount of organic matter could not be determined in the presence of the large amount of calcium carbonate.

Mechanical analyses of soils on experiment farm.

Class (loam).[a]	Depth.	Fine gravel, 2–1 mm.	Coarse sand, 1–0.5 mm.	Medium sand, 0.5–0.25 mm.	Fine sand, 0.25–0.1 mm.	Very fine sand, 0.1–0.05 mm.	Silt, 0.05–0.005 mm.	Clay, 0.005–0 mm.
	Inches.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Brown sandy	0–10	0.8	7.4	6.5	18.6	36.9	12.3	17.5
Brown	10–30	1.4	6.7	5.7	16.2	33.5	13.0	23.5
Brown sandy	0–12	1.1	6.2	5.7	22.4	34.5	13.6	16.5
Do	0–18	.3	3.8	4.5	27.4	38.4	12.1	13.5
Yellow sandy	18–30	.4	2.8	3.2	18.5	33.6	19.2	22.3
Brown sandy	0–20	1.1	6.1	5.2	30.0	34.0	9.9	13.7
Fine sandy	0–36	.0	.7	.7	18.1	38.7	25.9	15.9

[a] Coarse gravel not considered.

The soils of the prairie lands usually lack humus, and these analyses show the organic matter reaching a maximum of only 2.1 per cent on the cultivated land. The soil on the Cheyenne farm is light and is deficient in those qualities tending to produce nitrifying bacteria. This condition may be remedied by rotation of crops and the application of green or stable manures. The second part of the table shows the analyses of soils from a wide area about Cheyenne, and verifies the lack of humus in the prairie soils. It is interesting to note the excess of water-soluble salts in the broad prairie soils and that of the creek bottom in comparison with the soil of the farm. This lack of soluble salts in the soil of the farm shows that the tracts have free underdrainage, which is an admirable condition for intensive farming under regular summer irrigation, but not for storing water by winter irrigation.

CLIMATE AND RAINFALL.

The Cheyenne farm has an elevation of 6,000 feet above sea level, lies about 41° north latitude, and is often subject to low temperatures. During the winter months the thermometer sometimes registers several degrees below zero, but on account of the low relative humidity the cold is not keenly felt by man or beast. The low temperature, however, has a marked effect upon most winter grains when not well supplied with moisture at the time of planting. The spring is usually late and is accompanied by heavy winds, while the summers are short and cool. The growing season, therefore, is not long, but most crops, especially those properly selected, grow remarkably fast and usually mature before the killing frosts of fall. Most of the rain falls during the spring and summer months and is usually accompanied by thunderstorms. Hailstorms are not uncommon and seem to visit the same limited area, or travel in narrow paths across the country at each occurrence. Unfortunately, the Cheyenne farm seems to lie within one of these areas, having been visited each year by a storm of this character, which has interfered materially with obtaining satisfactory results.

The average precipitation for thirty-eight years, as recorded by the U. S. Weather Bureau station at Cheyenne, is 13.7 inches, but for the last five years the average annual precipitation has been 17.5 inches, or 3.8 inches above normal. In 1908 the occurrence of the summer rains was most beneficial, and during the growing season, which includes the months of May, June, July, and August, 13.4 inches of rain fell. This is more than has ever been recorded heretofore during these months. The spring-planted crops were well supplied with moisture for full growth and maturity.

The following table, taken from the Weather Bureau records, gives the monthly precipitation for the years 1905 to 1908, inclusive:

Monthly precipitation at Cheyenne, Wyo., for the years 1905–1908.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1905	0.84	0.69	1.80	1.80	2.45	1.58	2.14	1.41	0.99	0.70	0.40	0.38	13.70
1906	.21	.21	2.27	3.10	1.30	2.42	1.89	.49	1.86	2.33	1.42	.15	17.65
1907	.42	.49	.49	1.32	2.78	.34	3.56	.80	.92	.08	.59	.55	12.34
1908	.59	1.14	.09	2.45	4.33	2.52	6.19	.36	.16	.20	.36	.70	19.09
Mean for 38 years	.39	.52	.94	1.80	2.45	1.58	2.14	1.41	.99	.70	.40	.38	13.70

Existing records do not show that the climate has changed materially, nor is it possible to prophesy, with the records at hand covering such a comparatively short period, what the climate of the next decade will be. The precipitation of the past five years is excessive, but if the complete records are reviewed other periods of excessive precipitation are found, separated by years of drought.

The following table, compiled from the Weather Bureau records, shows the amount of precipitation above or below normal each year for five years at representative stations in the semiarid belt, and figure 1 shows this variation graphically, the irregular lines showing the annual precipitation, and the similar horizontal lines showing the normal:

Amount of precipitation above or below normal, 1904–1908.

Station.	1904.	1905.	1906.	1907.	1908.	Total below normal.	Total above normal.	Excess above normal (5 years).	Normal annual rainfall.	Number of years record.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	
Dodge City, Kans	−2.42	+ 6.35	+12.93	−0.87	0.00	3.29	19.28	15.99	19.61	42
Amarillo, Tex	−0.72	+10.63	+ 2.87	−3.96	−3.00	7.68	13.50	5.82	22.05	17
Miles City, Mont	−3.42	− 0.15	+ 4.15	+2.02	+6.60	3.57	12.67	9.10	12.56	31
Cheyenne, Wyo	+3.02	+ 8.98	+ 3.95	−1.36	+5.39	1.36	20.34	18.98	13.70	38
North Platte, Nebr	+4.42	+ 8.06	+ 9.24	+0.86	+1.21	0.00	23.79	23.79	18.75	34

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The algebraic sum of these five annual differences ranges from 5.82 inches to nearly 2 feet. This, when added to the annual mean, gives an amount of moisture which, if properly conserved, ought to produce without irrigation many crops. But, unfortunately, other

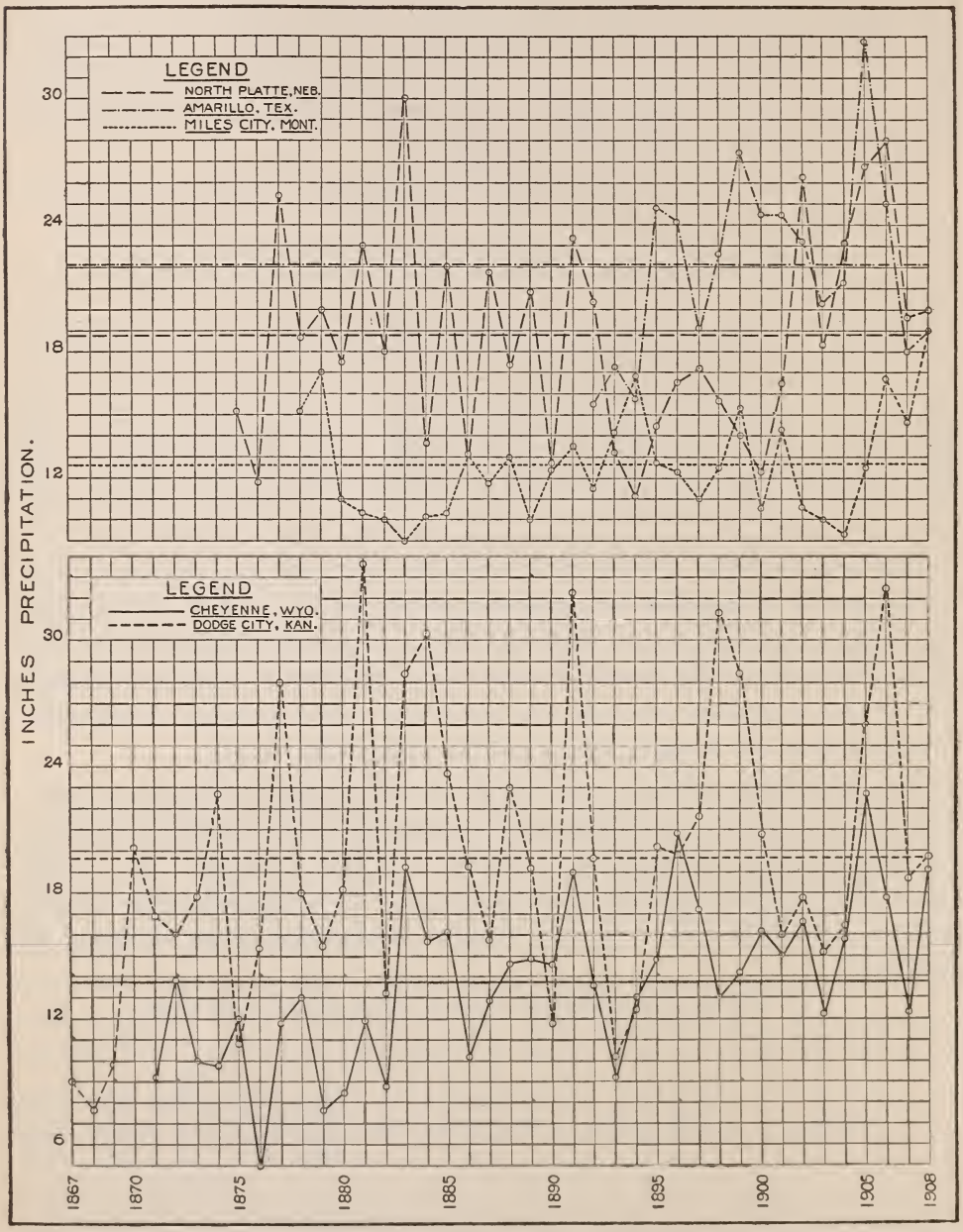

FIG. 1.—Chart showing annual precipitation and variation from the normal at points in the semiarid region.

five-year periods may be chosen in which the precipitation is much below normal. It is during these periods of scant rainfall that the farmer must be prepared to save a portion of his crops by an artificial supply of water.

It is sometimes, but erroneously, assumed that the records of precipitation mean that the amount of water recorded has permeated the soil and is retained for the use of crops. In the semiarid belt rain often falls in great quantities in a short time, records showing in many instances an inch or more in an hour. Coming in such a violent manner it is impossible for the entire amount of water to penetrate the soil, and necessarily a large percentage of the precipitation is lost by run-off into draws and meandering creek beds, the amount varying with the configuration and condition of the surface of the land. Then again, light showers occur in the middle of the day, with the sun appearing immediately afterwards, and the moisture the surface of the soil has received is soon evaporated, leaving a crust and restoring capillarity. Unless the crust is broken immediately and a mulch restored a large amount of moisture is lost by the soil beneath.

Latitude and altitude have a marked effect also upon the available moisture in the soil. In localities where the ground freezes a foot or more in depth and remains frozen all winter, only the very early and very late snows have any perceptible effect upon the moisture content. When the soil is frozen, the snow either evaporates directly or is melted slowly and evaporates without being able to penetrate the solid earth. In southern portions of the semiarid belt, where higher temperatures prevail and the conditions are more favorable, the winter snows are more effective.

The temperature of the semiarid belt varies greatly from the northern to the southern part, and from higher to lower elevations. The farther north one goes the greater is the annual variation. In the extreme southern part of Texas, where the Gulf moderates the temperature, there is an annual variation of 100° compared with a variation of 160° in North Dakota. The following table shows the effect of latitude and altitude on temperature:

Effect of latitude and altitude on temperature in the semiarid belt.

Station.	Latitude.	Altitude.	Mean annual temperature.
	° ′	*Feet.*	° *F.*
Miles City, Mont.	46 27	2,371	44.2
Cheyenne, Wyo.	41 7	6,088	44.9
North Platte, Nebr.	41 7	2,821	49.2
Dodge City, Kans.	37 42	2,513	53.4
Amarillo, Tex.	35 11	3,676	55.1

Thus in the same latitude as Cheyenne, Wyo., but with 3,200 feet difference in elevation, North Platte, Nebr., has an increase in mean annual temperature of over 4°. The variation in latitude presents a still greater difference in temperature. These differences should produce a marked effect in the growing and maturing of general farm crops.

NATURE AND PURPOSE OF EXPERIMENTS.

To show clearly the advantages of a small water supply and more particularly that secured by means of windmills, a tract of 5 acres on the Cheyenne farm was divided into five equal parts, planted to different crops each year, and irrigated when necessary. Directly adjoining this tract is a similar area devoted to crop raising with natural precipitation alone. In every case plats planted to like crops are treated in the same manner with reference to preparation of seed bed, planting, and cultivation, with the exception of the irrigation. Crop rotation is practiced after no particular method, but is always the same for the two plats to be compared. Water is supplied from a small reservoir which is filled from wells by windmills. Under this reservoir is also a small area devoted to fruit trees, grapes, berries, and a general vegetable garden. Adjacent to this plat is still another where the growth of similar kinds of trees, vines, vegetables, etc., has been attempted without the artificial application of water. In addition to these various plats many trees have been planted to form wind-breaks and ornamental driveways. A small lawn has been established and small beds of flowers flourish. With even a limited amount of water the latter may be had and add much to the comfort of the rural home.

Thirty acres of the south farm are irrigated, sometimes once, and often twice, in the fall and spring, with a heavy flow of water. There are six plats of 5 acres each in the tract, five of which are planted to grain and potatoes each year, while the sixth plat produces an annual crop of alfalfa. Water is supplied in winter from the unappropriated flow of Crow Creek and is carried to the tract by a small open ditch.

WATER SUPPLY.

For the experimental work first mentioned two windmills were secured. These were located upon the bench land where the water level occurred about 20 feet from the surface of the ground. Neither of these mills proved entirely satisfactory, partly on account of their construction and partly because the pumps were placed at the ground surface and had too long suctions. These mills were replaced by another which was located on the creek bottom about 20 feet lower than the land to be irrigated. This provided a dependable supply of water, though it was necessary to pump against a greater head with the mill in the new location. This increased distance (some 300 feet) from the original site naturally caused an additional friction head to the water flowing in the delivery pipe. This pipe line was composed of 4-inch asphalt-dipped, riveted-joint pipe made in sections 12 feet long and slipped together after the asphalt at the joint

had been heated. The use of such a pipe, while convenient and inexpensive, can not be recommended for long lines unless a size be adopted much larger than would be necessary if the pipe were smooth, such as wrought iron or steel, having flush joints.

The original plant included an earthen reservoir rectangular in shape, 200 feet long, 100 feet wide, and 3 feet deep. The embankment was thrown up with a slip scraper and had, when completed, a 1 to 3 inside slope and a 1 to 1 outside slope. The character of the material of which the reservoir was constructed was very poor, consisting of a sandy gravelly soil almost devoid of clay. It was thought, however, that with proper puddling and with manure added it could be made tight, but such efforts met only with failure. After continuous puddling for several weeks at a time and frequently repeated, it was possible to retain a small amount of water; but it was late in the irrigation season before even such partial success was attained.

With a view to lessening the seepage and yet making feasible the irrigation of a part of the land selected, the reservoir was reduced to one-half its original size by building a partition across the center, thus reducing the seepage loss one-half. It was now possible to conserve sufficient water to demonstrate in a small way that windmill irrigation was feasible, though to what extent could not be determined with such unfavorable storage facilities. During the winter of 1907 it was decided to divide the reservoir again, making two smaller compartments, and to make a separate study of reservoir lining to prevent seepage loss.

To broaden the work, and at the same time increase the water supply, it was thought best to increase the number of mills by adding others of different makes, thereby making possible a study of the various mills when operating under identical conditions. The results of these tests of windmills are included in other reports now being prepared for publication.

The original pipe line leading from the mills to the reservoir was found to be much too small to permit the simultaneous operation of the five mills, as was shown by the friction head measured by a pressure gauge placed at each pump discharge. There was a very great "water hammer" in the pipe line as well, though this was materially reduced by the use of additional air chambers placed upon the pumps at the points of connection with the pipe line.

The wells supplying water to the mills were 4 by 4 feet, and from 6 feet to 8 feet in depth, the water rising to within 2 feet of the surface of the ground. The formation in which the wells were dug is coarse sand, gravel, and quicksand, giving an abundant water supply. Each well was dug sufficiently deep to supply by test 60 gallons per

minute. The curbing in the wells was made of 2 by 12-inch Oregon pine placed behind 4 by 4-inch corner posts, the entire crib being driven with a sledge as the excavation proceeded.

The pumps were all of the pressure type, having the cylinders placed below the water level, connected by a 4-inch pipe to a pump head of the simple guide and cross-head type, except one, which was of a special siphon type. The pump heads are supported upon 2 by 12-inch joists securely braced and nailed to the sides of the curbing. In each instance the entire pump is below the ground surface, so that the well may be floored over and covered with manure to protect it against frost during the winter months. Each pump is also provided with drain cocks so as to properly drain during calm, cold days.

All the new mills were connected with the original main pipe line by 4-inch wrought-iron pipe with screwed joints. At each pump was installed an integrating impulse meter, whereby a record of the quantity of water pumped could be obtained. These meters were read three times each day. A record of the wind movement was likewise kept by a recording anemometer.

The success attained with the reservoir during the latter part of the season of 1907, when four mills were in operation, was not pronounced, though in 45 days these mills delivered to it 7.1 acre-feet of water. Experiments were then started upon reservoir linings. Formerly the water was drawn off from the reservoir through simple wooden gates and a flume 12 by 18 inches, the water discharging into small ditches, through which it was conveyed to the various plats, but the subdivision of the reservoir left two of the small compartments without means of discharge, and 6-inch galvanized-iron pipe of No. 18 gauge was used as discharge from all three compartments, each of which connected to the main pipe by branch wyes controlled by quick-closing lever-handle water-gate valves.

During the latter part of the summer of 1907 renewed efforts were made to make impervious the larger of the three compartments of the reservoir, as it was realized that if success were attained in windmill irrigation it must be at a small cash outlay, and if by any cheap means available to the farmer a reservoir of such poor material could be made tight it would demonstrate unquestionably that expensive treatment of the banks and bottom of a reservoir need not be resorted to. Late in the season, when the water was of no immediate value to the crops, the reservoir, after being puddled with manure, was again filled and the water allowed to evaporate and seep away, while a record of its subsidence was kept. One of the small compartments, having a capacity of 0.29 acre-foot, was treated with tar, the bottom and banks being raked to a mulch 2 inches deep, and the tar in a boiling state poured thereon by means of pails

with long handles attached, the bottom of the pails being perforated with small holes. It required 504 gallons of tar, equal to 0.121 gallon per square foot, to cover the area, and the cost, including labor, was close to 1.1 cents per square foot. Water was then turned into the compartment, and its performance was observed in comparison with the larger unlined compartment. The average loss in the tar-treated compartment was equivalent to 1.58 feet for 24 hours, or more than twice that of the unlined reservoir, which was equivalent to 0.72 foot average per day of twenty-four hours, and in view of the fact that the times of observation were identical, the evaporation losses therefore being practically the same for each compartment, the difference between the two must have been really due to seepage. No attempt was made during these experiments to segregate the seepage and evaporation losses, though the next season such experiments were conducted. While the natural or unlined reservoir showed practically no reduction in loss at the end of twenty days, in the tar-lined reservoir the loss became constantly less. This is due to the fact that the former requires a considerably longer time to become impervious, while the natural settlement of the mulch in the tar-lined reservoir tended to reduce the loss after constant use for a short time, but even so at the end of the test it was about twice that of the puddled reservoir. The effect of wind and temperature was nearly the same for each compartment, so that this influence could not account for the relative difference.

The cold weather having set in, it was impossible to continue these experiments further and they were postponed until the next season, when the second small compartment was treated with tar by thoroughly settling the banks and bottom with water and allowing it to dry out, when two coats of hot tar were applied, the first coating requiring 0.1 gallon per square foot and the second coating requiring 0.06 gallon per square foot. The ground, being so firmly packed, did not take up as much of the tar as when the surface was mulched, and the second coat seemed to seal the voids, making a smooth, glossy surface. This compartment was then, about April 1, put into service, but the loss from seepage and evaporation was very great, averaging 0.93 foot per day of twenty-four hours. At the same time the large compartment was again thoroughly puddled and the loss became less, until it did not exceed 0.35 foot per day of twenty-four hours. It was impossible to reduce the loss beyond that amount, notwithstanding nine sacks of Portland cement were emptied over the surface and allowed to settle to the bottom, and the bottom again puddled.

In view of the imperative necessity for a dependable supply of water for the crop experiments it was decided to resort to a concrete lining for the large compartment. It was necessary to use the small com-

partments for storing water for use in the concreting of the larger reservoir, so the small section tarred last was filled with water and observed until the latter part of June.

Owing to the scarcity of skilled labor the work of lining the reservoir with concrete was handled by contract, while material was paid for according to amounts used. Because of the possibility of seepage from the adjoining compartments which, owing to the slope of the land, would pass underneath the proposed concrete section and possibly freeze during the winter, thus causing cracks in the banks and bottom of the concrete, it was thought best to drain the soil beneath the concrete, and for this purpose 4-inch glazed terra-cotta tile were carefully laid in three divisions at right angles to the direction of the flow of the drainage water. The lines were started about 12 inches below the bottom of the finished concrete and given a uniform grade of 11 inches in a distance of 100 feet. The ends of these drains were left open, so that measurements of the quantity of water flowing could be made. The drainage water was discharged into an abandoned well adjoining the site.

The banks of the section to be lined with concrete were carefully and uniformly trimmed to a slope of 1 to 1 and the bottom was reduced to a plane and given a slight slope toward the outlet gate controlling the discharge. The depth of rough-body concrete was 3 inches, while the top surface was finished with a sand-cement coat one-half inch thick. All corners and joints between the bottom and the sides were reenforced with $\frac{1}{4}$-inch round iron rods spaced 10 inches between centers. A heavy fillet of concrete was used at these junctions to insure ample compressive area. The rough body concrete consisted of one part, by volume, of Portland cement to three parts sand and four parts of fine and coarse gravel, while the finish coat consisted of one part Portland cement to one and one-half parts of clean coarse sand.

Owing to the imperative need of water, it was necessary to rush the work with all possible haste, and a concrete-mixing machine was used as well as a large force of expert concrete workers. The work was so arranged that a strip 10 feet wide was finished entirely across the reservoir before another portion was begun, and the dress or finish coat was applied as fast as the rough body work was tamped to place. This method prevented checking of the concrete at any except predetermined places.

The exceeding dryness of the air and high temperatures tended to cause too rapid drying of the dress coat, which might have produced blisters or checks. Before the cement had taken its initial set it was too soft to spray, so long strips of canvas were laid upon the concrete and kept wet by sprinkling. After twelve hours of such wetting it

was possible to remove the canvas to another near-by strip and apply water directly to the strip exposed. At no time during the entire progress of the work was the cement allowed to dry out, and the wetting was continued until the strength was sufficient to sustain the weight of water when filled. The area being a large one and subject to considerable temperature change, the expansion was cared for at the unions between the strips of work, and in no other place were checks discernible.

The quantity of material required, together with the labor, was as follows:

Cost of cement lining of reservoir, Cheyenne.

Labor on rough body work, equivalent to one man 80 days, at $3 per day	$240.00	
120 barrels of cement, at $1.89 per barrel	226.80	
144 yards gravel and sand, at $1 per yard	144.00	
Labor on finish coat work, equivalent to one man 36 days, at $3 per day	108.00	
Sand, 44 yards, at $1.50 per yard	66.00	
Cement, 52 barrels, at $1.89 per barrel	98.28	
Cost, exclusive of earthwork		$883.08
Equivalent cost per cubic yard of work, $6.13.		
Tile, 350 feet, at 2½ cents per foot	$8.75	
Labor, ditching and laying tile	12.00	
Original cost of reservoir (estimated)	150.00	
Labor, trimming banks, including team and scraper	60.00	
1,000 pieces ¼-inch round iron 24 inches long, for reenforcement	15.00	
Total		245.75
Cost of reservoir complete		1,128.83

The reservoir, as now completed, has a capacity of 0.8 acre-foot, making a cost of about $1,400 per acre-foot of capacity, notwithstanding the fact that the cost of this work, $6.13 per cubic yard for concrete work, was much less than usual. Still the cost is too great to be borne by the farmer in ordinary circumstances, and where the material of which a reservoir would have to be constructed is of such a character as to resist puddling successfully it is not feasible to attempt irrigation of even small areas by windmills. Of course the capacity of the reservoir might have been increased to several times its present amount by extending the walls higher, and the cost would not have increased in the same proportion, but it would have required at least a year to settle the added embankment, for it is impracticable to line with concrete a reservoir which has not had sufficient time to settle and pack firmly. It is not impossible to tamp and so settle the embankment during construction, but the results are not entirely satisfactory, and such lack of settlement of newly made footings is the cause of a very large percentage of concrete failures.

Experiments upon evaporation loss were made while determining the seepage loss from both the concrete-lined and the last tar-lined compartment. The seepage in the concrete-lined section was so insignificant as to be beyond reading. The loss, therefore, from this compartment is that from evaporation only. The average loss by evaporation per twenty-four hours was 0.25 inch or 0.02 foot. In the tarred compartment the loss at the start was nearly 0.5 foot per day, while at the end of twenty-one days the loss became nearly constant at 0.07 foot per day of twenty-four hours, from which should be deducted the average evaporation loss, leaving about 0.05 foot per day as the average seepage loss for this compartment.

The conclusions drawn from the experiments in reservoir lining at Cheyenne are possibly applicable only to localities where the soil is porous and resists puddling. Whether the soil is of this character or not, the freezing of an unlined reservoir during the winter months, as was found by experiments, tends to so disturb the ground as to make it very porous in the early part of the spring season. It should be thoroughly puddled as soon as the frost is out of the ground. Several tests were made upon the Cheyenne reservoir after allowing it to dry out. It was found that the seepage loss at such times is enormous, and where a reservoir is allowed to stand for even a day without water, it should be again puddled before being put into use. If possible, it would be beneficial to allow water to remain in the reservoir during the entire winter. It is not impracticable to use a reservoir for the harvesting of ice, which can be stored in an inexpensive shed for use during the summer months. Where such use is made of a reservoir, and especially if it be a lined one, the ice should be cut free around the bank line so as to prevent the excessive lateral strain due to freezing.

The square or rectangular reservoir is not the most economical shape to construct, and where subdivisions are not necessary the circular type will be found cheaper in construction and easier of maintenance. Prior to the lining of the Cheyenne reservoir great trouble was experienced from wave cutting of the banks upon the sides facing the direction of greatest wind prevalency. The inner slope, though 1 to 3, was gradually eroded until the slope was as low as 1 to 15 at the bottom. This trouble was remedied by floating around the edges old ties tied together by short cleats. It is possible to greatly lessen the evaporation loss by planting some low bush tree thickly along the top of the embankment, and this was done at the Cheyenne station, a bush willow being used.

The feasibility of windmill irrigation is dependent not only upon the success of storage facilities but to a large extent upon the cost of maintenance of the windmill plant. With a view to obtaining the actual cost of such maintenance a record was carefully kept

showing the character of repairs, the repair parts and their cost, together with the time required upon these repairs and the time actually given to each mill to keep it in proper operating condition. Upon this subject much could be said, though the conclusions are confined to those drawn from experiments with the wells at this station only.

At the outset it was supposed that the regular farm laborer could occasionally inspect and oil the mills and that no additional attention would be required. This method was employed during the latter part of the irrigation season of 1907, but the result proved disastrous to the mills. While the attention given the plant was thorough and painstaking, any slight trouble, which if observed at its inception could have been corrected, developed into a serious damage before the mills were again examined. While it may be possible that the excessive water-hammer in the discharge line was to some extent responsible for more or less of this trouble, the conclusion was reached that the mills must have regular inspection daily, with the exception of but one type, the direct-stroke wood-wheel variety. The reason for this exception is very plain, for in the direct-stroke type there are but few moving parts, the loosening or wear of which (due to lack of oil or collection of dust) would affect its operation, while with the back-geared type any unequal wearing of bearings or loosening of check nuts will impose unequal strains which may break the gears or cause unequal wearing. Indeed, the results of neglect to this type of mill could not be described, so numerous are they. It is not the intent of this conclusion, however, to cast reflection upon the geared type of mill, for it possesses advantages with regard to loading not possible in the direct-stroke type, but it is the purpose to urge systematic inspection of a mill where it must be constantly used, as for irrigation purposes.

The following is a table of the performance of the mills referred to, together with a statement of the water pumped, cost of plant, cost of operation, maintenance, repair charges, and the equivalent costs per acre-foot and per horsepower-hour.

Costs of operation of mills at Cheyenne station.

Mill No.	Cost of repair parts.	Cost of labor, maintenance of mills, at 6 cents a day.	Cost of labor on repairs, $2 a day, 10 hours.	Annual interest charge on entire plant, 8 per cent.	Total annual cost operation of mill plant.	Equivalent cost per acre-foot.	Initial cost of plant, including wells.	Equivalent cost per horsepower-hour.
1.....	$6.50	$3.60	$1.50	$22.16	$33.76	$16.08	$277.00	$0.22
2.....	5.20	3.60	5.60	18.96	33.36	19.28	237.00	.27
3.....	5.05	3.96	.80	19.76	29.57	16.24	247.00	.22
4.....	42.84	2.13	15.40	17.20	77.57	59.21	215.00	.82
5.....	1.50	3.36	6.00	18.08	28.94	11.35	226.00	.17
6.....	55.05	3.60	10.40	20.16	89.21	(a)	252.00	(a)

a Out of service.

Character and performance of mills at Cheyenne station.

Mill No.	Description of mill.	Size of pump cylinder.	Total horse-power-hours work done.	Average horse-power per hour.	Number of hours mill operated.	Cubic feet of water pumped in that time.	Acre-feet water pumped.	Total miles of wind.	Average rate of wind, miles per hour.
1.....	12-foot steel, back geared.	6-inch cylinder, 12-inch stroke.	150.34	0.105	1,432.25	91,598	2.10	18,408.00	12.86
2.....	.....do.....	6-inch diameter, 10-inch stroke.	124.03	.087	1,418.25	75,567	1.73	19,584.75	13.81
3.....	.....do.....	5-inch cylinder, 10-inch stroke.	130.48	.083	1,574.25	79,492	1.82	21,561.50	13.69
4.....	14-foot steel, back geared.	6-inch diameter, 12-inch stroke.	94.08	.111	843.75	57,315	1.31	11,671.00	13.83
5.....	16-foot wood, direct stroke.	6-inch cylinder, 8-inch stroke.	165.68	.123	1,342.50	110,939	2.55	16,111.50	12.01
6.....	14-foot double steel, forward gear.	8-inch by 10-inch twin cylinder.	Not in service.						

In conclusion, it is fair to state that the repair charges upon mills Nos. 4 and 6 are exceedingly high, and are not representative of the performance under different conditions, due to the fact that in heavy winds both of these mills were badly damaged, though the fact remains that the other mills experienced similar severe strains without damage. While these failures were attributed to inherent defects in manufacture, they might have been remedied had systematic inspection been given at the outset. The pump on mill No. 4 was damaged by the freezing of water in the bonnet. The pump being of the siphon type could not be as effectively drained as those of the ordinary type. This could have been avoided by a second system of drains, or by lashing of the mill wheel, thus preventing its making an occasional stroke when cut out of service, as all mills will do when shifting with changes of the wind direction.

It will be seen that the cost per acre-foot of water pumped is high, even with the mill having the least expense, i. e., the direct-stroke type, but it should be remembered that the charges include interest, which is not a cash outlay, and, further, that the head under which the mills operate is 52 feet, which is rather a high head for windmill pumping plants where large volumes of water are required for irrigation purposes.

Before the reservoir was lined with concrete it was a difficult matter to irrigate 5 acres of land with all the mills, but it is not unreasonable to assume that at least 20 acres of land can be irrigated during the subsequent years, if all the mills are operated, or probably 5 acres from any one mill, if the mills are not operated simultaneously.

PREPARATION OF THE LAND.

Much time and labor were spent in preparing the 5 acres and garden tracts of the north farm for irrigation. In order that water can be distributed economically the surface of a field or plat should approach

a plane as nearly as possible and should invariably have a gentle slope. If flooding or irrigating in furrows from a head ditch is resorted to, the slope is essential; but if distributing pipes are used the slope is not so important and the plat may be quite level. In every case all knolls should be removed and all depressions filled. While the first cost of careful grading may be high, the great saving in both water and labor in subsequent seasons will more than neutralize the initial expenditures. The land was first plowed; then the high knolls were removed by the use of a scraper. Wherever necessary the plow was used a second time, the harrow following, and lastly the land grader or leveler in its simplest form was drawn several times over the plats, reducing them to a plane surface having a gentle slope to the east and south.

The land on the south farm was fairly level and with plowing and harrowing each year the surface presents no serious obstacles to the distribution of water in winter irrigations. Where the land is flooded with 2 to 3 feet of water in one irrigation in the fall or winter while uncropped, it matters very little how the water is applied so long as it completely fills the subsoil.

METHOD OF APPLYING WATER.

During the first year's experiments, water was taken from the reservoir and delivered to the plats through a small open ditch. The soil being so porous and some of the plats lying so far from the reservoir made this method impracticable where such a small head of water was used. The following year a portable pipe system was installed. Six-inch pipes, 16 feet long, were made of No. 20 gauge galvanized iron, riveted and soldered at all joints and seams. One end of the pipe is slightly smaller and tapered, so that the sections are readily slipped together in the field with a comparatively tight joint. If a block of wood is held over one end of the pipe they may be driven together lightly. The original cost of this pipe was about 22½ cents per foot. If carefully handled such pipe will last a long time, making the cost per acre very low. The sections are usually joined together with elbows of such degree that the open end of the pipe is at the lower end of the plat. Water is admitted from the reservoir through a gate valve and flows to the lower end of the plat. After sufficient water has been applied on that portion of the plat the last section of pipe is removed and the adjoining portion of the plat watered. This is continued until the entire plat has been carefully irrigated. With this method no water is lost in transportation. For potatoes a slightly different method is used. The fact that it is poor policy to allow irrigation water to come in direct contact with the vines precludes flooding and the furrow system of irrigation is used.

The head of water delivered by the pipe is divided into four or five streams and allowed to flow slowly through as many furrows until the water reaches the opposite end of the plat. This usually takes an hour. The stream is then diverted into other furrows until the entire plat has been irrigated with an amount of water equal to a depth of 3 or 4 inches over the surface.

Where winter irrigation is practiced, just before the first irrigation in the fall contour ditches are made through the fields by means of a moldboard plow followed by a V crowder or ditcher. Water is turned into two or three of these ditches and carried to a predetermined point, where it is stopped by a dam which causes it to overflow and flood the field. After it has run for several hours the ditch is dammed at another point, where the flooding again takes place. This movement is repeated until the entire area is irrigated. Several days are required with a 4 or 5 foot head to cover the whole field. It has been customary to give the entire 30 acres a heavy irrigation in the fall, and the north half of 15 acres a similar irrigation in the spring. This was done in order to determine the feasibility of a spring irrigation in conjunction with the fall watering. Owing to the position relative to the creek bed and complete underdrainage, no particular difference was noticed in the yield of alfalfa. This plat was influenced less by its location, and the differences in the growth of the plants was quite marked. In the spring of 1909 the south 15 acres were irrigated instead of the north half, and being less under the influence of the creek the benefit of this later application of water was readily observed in the newly sprouted grain.

SUMMER FALLOWING.

Summer fallowing has been successfully practiced on the Cheyenne farm since the beginning of the experiments. Although several different crops have been tried with encouraging results, potatoes have given the greatest returns.

Summer fallowing originally consisted in merely overturning the soil with a plow and allowing it to absorb the water from the rains, remaining otherwise untouched until time for planting, a year hence; but the term is now applied to the treatment of the soil that has been plowed deep and is in a continual state of cultivation, but with no growing crop. Weeds which uselessly abstract the moisture are removed and a protecting blanket of dust mulch is retained. Portions of two years' precipitation are thus stored in the soil for the benefit of one season's crop production, and one-half of the farm only is producing crops annually. While the benefit of summer fallowing is due, in part, to an increase of bacteria and other microorganisms and a slow process of breaking down of soil particles into available plant food by the continual presence of excessive moisture

and aeration of the soil, yet the moisture thus retained is, no doubt, the greatest influencing factor in this system of agriculture. The moisture content is shown in an experiment by the Montana Experiment Station[a] where the moisture was found to be three times as great in the first 7 feet of soil in a summer-fallowed tract as in one growing crops.

Soil-moisture determinations made each year on summer-fallowed plats on the Cheyenne farm show conclusively the results of this practice. Figure 2 is a graphical representation of the relation of the moisture in two of the summer-fallowed plats from April 18 to October 2, 1907. One of these plats was fallowed in 1906 and cropped

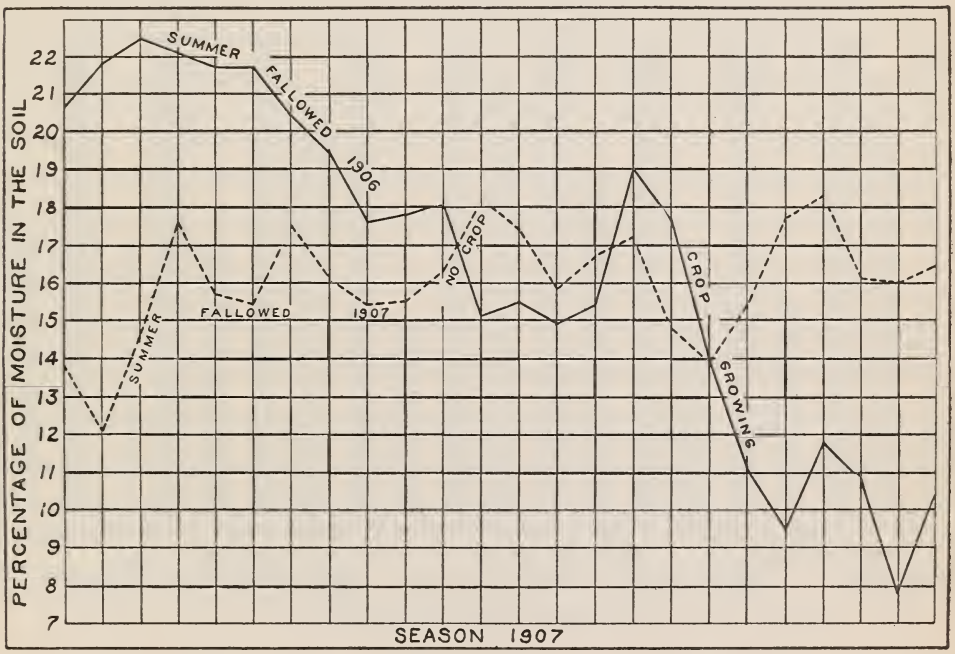

FIG. 2.—Graphical representation of the relation of moisture in cropped and uncropped summer-fallowed plats, April 18 to October 2, 1907.

to potatoes in 1907. The adjoining plat was fallowed in 1907 preparatory to growing crops in 1908. At the first of the season the plat fallowed in 1906 contained much more moisture than the one adjoining, for crops grown on the latter the preceding year had taken the water from the soil. During the season, however, the crops planted in 1907 required the water and gradually reduced the moisture content until there was less moisture in the cropped plat than in the one uncropped. The plat summer fallowed in 1907, having produced a crop in 1906, was deficient in moisture, but gradually collected the precipitation and retained the water till the end of the season, when it showed about 6 per cent more moisture than the one adjoining.

[a] Montana Sta. Bul. 74, Dry Farming Investigations in Montana.

In practicing summer fallowing upon the Cheyenne farm it has been customary to plow as early in the spring as possible, double disking the land first if necessary, then following with a spring-tooth harrow or spike-tooth harrow. The land is harrowed several times during the summer to keep the plats free from weeds and to reduce the soil to the proper tilth, not only for receiving the moisture, but to retain it.

Figure 3 shows the yields produced on continuously cropped dry-farmed land in comparison with the yields produced on summer-fallowed lands. In years of scant rainfall the difference would probably be more noticeable.

In the practice of summer tillage the use of a subsoil packer is

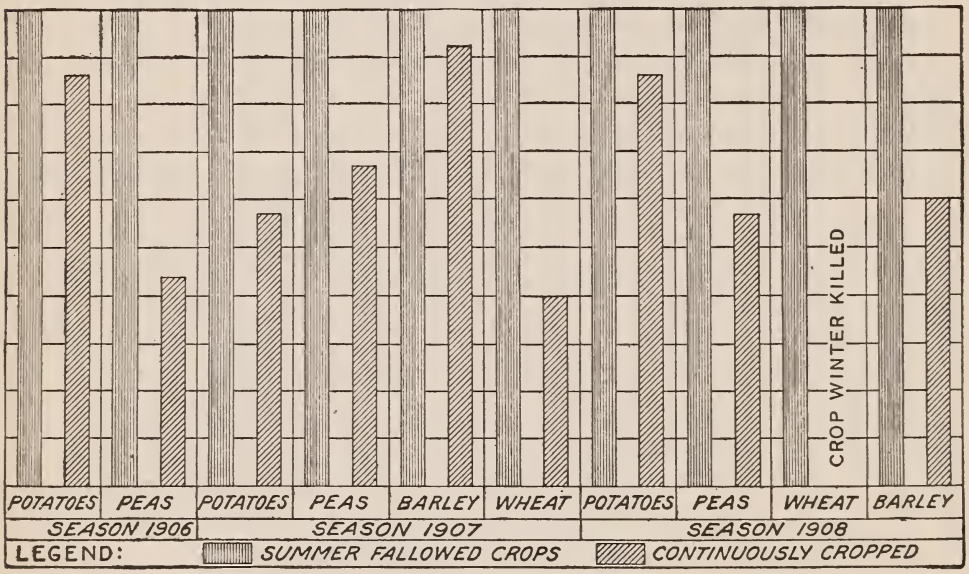

FIG. 3.—Diagram showing relative yields on summer-fallowed and continuously-cropped lands.

sometimes advocated. A subsoil packer can not be given a sweeping recommendation. Like every other implement it must be used with judgment. The condition of some soils might be benefited by its use while others would not. As a rule the soils of the semiarid belt do not require its use after they are once in a state of cultivation. It is an extra expense, and when crops are light expenses should be reduced as much as possible.

INTERTILLAGE.

Intertillage consists in cultivating grain or other crops between rows at opportune times during the early stages of growth in order to retain the moisture in the soil by a dust mulch. The rows of grain are spaced a convenient distance apart to allow free access with the cultivator and horses.

On portions of the Cheyenne farm intertillage has been practiced on various crops each year. An ordinary riding cultivator was adjusted by an implement manufacturer so that, with two horses, five spaces could be cultivated simultaneously. The wheels were so connected with foot levers that the driver could direct the course of the implement independently of the tongue. The shanks were arranged so that several different-shaped interchangeable tools could be used to stir the ground. By means of a hand lever the depth of cultivation could be regulated. Although at the beginning of the work it was intended to experiment with various attachments as well as to try deep and shallow cultivation, it was found after a single trial that only the very narrow cultivator teeth could be used with any satisfactory results, as the other blades all injured the plants to an alarming extent. Deep cultivation was found impracticable and early cultivation could not be practiced on account of covering the small tender plants with soil. After a complete trial it was found desirable to remove three sets of the cultivator teeth and work but two spaces at one time and also to abandon the use of the foot levers. At present the cultivator in use has fourteen 1½-inch teeth, divided into two sets of seven each, each set cultivating one space. With the cultivations in the latter part of May and the middle of June, when the grain is at a fair height, this implement works very well.

It is doubtful whether intertillage of grain can ever be practiced with satisfactory results. The yields may be increased slightly, but the increased cost of production will tend to neutralize any increase in profits. All the experiments in intertillage on the Cheyenne farm show negative results.

WINTER IRRIGATION.

Winter irrigation makes it possible to raise good crops of grain, potatoes, and alfalfa each year upon the same land, while without this irrigation summer fallowing would be necessary, which not only reduces the acreage by one-half, but may be an uncertain procedure. The yield of winter-irrigated barley in 1907 was almost four times that on an unirrigated, continuously cropped plat. Durum wheat yielded more than five times as much grain on a winter-irrigated acre as it did on one unirrigated and continuously cropped. In 1908 a little more than three and one-half times as much alfalfa was cut per acre on the winter-irrigated plat as on one unirrigated planted at the same time. Such increased yields mean much to an ambitious farmer and in themselves recommend the practice of winter and spring irrigation.

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RESULTS.

Some of the results of irrigation have been very pronounced, while others, owing to an annual visitation of hail, have not been what they would have been under normal conditions. It was very noticeable that irrigated crops, especially potatoes, revived from the effects of a hailstorm or heavy wind much quicker and to a greater degree than did any of the unirrigated crops. The irrigated potatoes not only yielded greater quantities, but the percentage of merchantable sizes

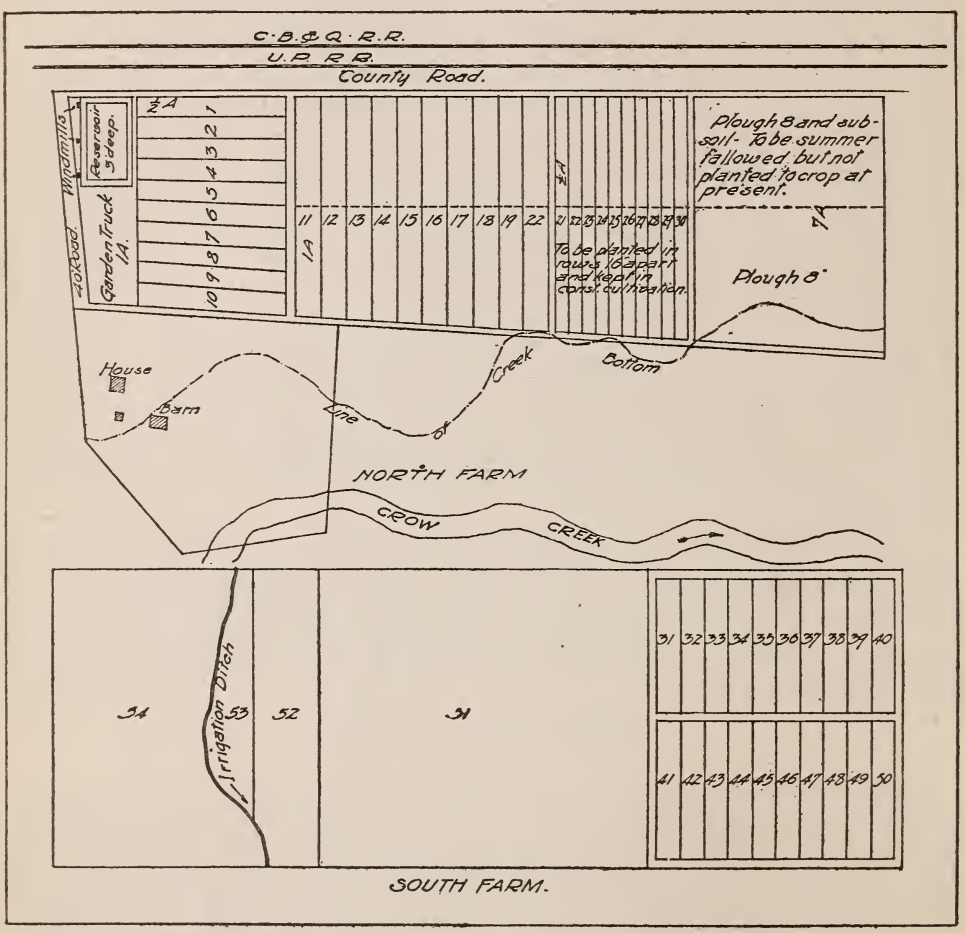


FIG. 4.—Map of Cheyenne farm, showing arrangement of plats in 1906.

was greatly increased over the others, with very few oversize. The arrangement of the plats in 1906 is shown in figure 4, and in 1907 and 1908 in figure 5.

Perhaps the most conspicuous results of irrigation have been with the winter wheats. In the fall of 1907 plats 5 and 6 were planted to Turkey Red wheat under exactly the same conditions, with the exception of one small irrigation given to plat 5 before plowing in the fall. The fall having been without rain, the seed bed in plat 6 was very dry, while plat 5, of course, was in excellent condition. On plat 5

the plants began to show plainly and seemed vigorous fourteen days after seeding. On plat 6 the plants began to show above the ground twenty-six days after seeding, but had a very weak appearance. The winter was unusually dry, with scarcely any moisture from the time of seeding until the 1st of May, with the result that the entire planting on plat 6 was winterkilled. Later in the season this plat was plowed to keep the weeds from gaining possession of the land. Plat 5 received a second irrigation the latter part of June. This moisture,

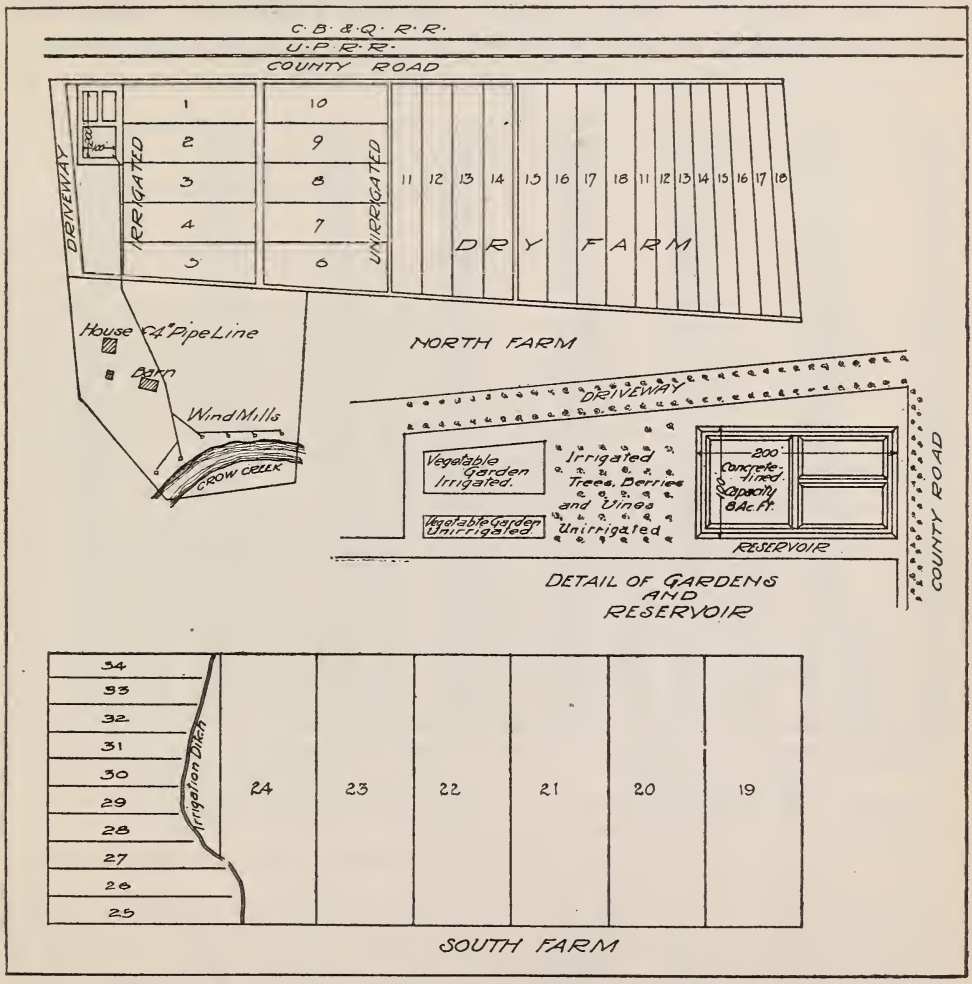


FIG. 5.—Map of Cheyenne farm, showing arrangement of plats in 1907 and 1908.

together with the natural precipitation, carried the crop through the season. A yield of 32.28 bushels per acre was obtained, which sold for seed at 2 cents per pound, and together with the straw brought $50 per acre. This experiment was tried again in the fall of 1908 and the indications in the spring of 1909 forecast a repetition of the experience of the previous year.

Plats 3 and 8 were planted to alfalfa in the spring of 1908. Plat 3, having the benefit of water when needed, had a much stronger,

denser stand of alfalfa than did the adjoining plat planted under the same conditions. Figure 6 shows the ratio of yields and in a comparative way shows the value of a small water supply.

Jonathan, Wealthy, and Winesap apples, May, Duke, and English Morello cherries, and Damson plums have been planted in both the irrigated and unirrigated orchards. The Wealthy has proven the most hardy of the apple trees. Some of the irrigated and all of the unirrigated trees have had to be replaced by new stock. While all of the trees were given plenty of water upon planting and received frequent cultivations during the season, it was very hard to get them to root properly. It has been demonstrated clearly that it is next to

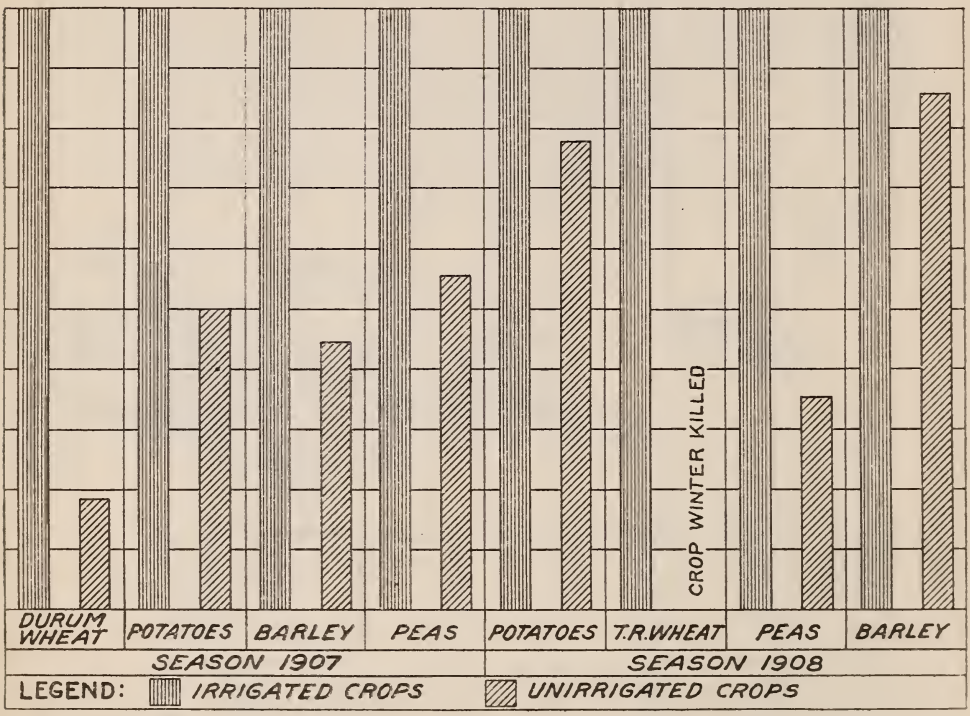


FIG. 6.—Diagram showing relative yields on irrigated and unirrigated plats continuously cropped.

impossible to grow a fruit tree to maturity without frequent irrigations and cultivations during the first few years after the tree is planted. Currants have taken more kindly to the prevailing conditions and some of the bushes have been sustained by the natural precipitation alone. Raspberries, blackberries, gooseberries, and strawberries on the unirrigated plat have been unable to withstand the drought of some portions of the year, but those irrigated have grown quite well. In this locality there are four factors influencing fruit growing, viz, scant rainfall, the cold of winter, and the winds and hail of spring and summer. In the selection of trees or shrubbery only those most hardy and, if possible, those indigenous to the country should be chosen. Cottonwood trees have proved the best

for shade and wind-breaks, but they, too, require frequent irrigation during the first two or three years of their growth. Carolina poplars have not been so successful.

In the garden, where a little more than one-tenth of an acre of land is irrigated, onions, beets, carrots, radishes, parsnips, turnips, leek, peas, cabbage, tomatoes, cauliflower, rhubarb, beans, sweet corn, squash, and asparagus have been grown. In 1906 several wagon-loads of squash which were grown in the small irrigated orchard were marketed. In 1907, notwithstanding the great damage done by two severe hailstorms, 790 pounds of cabbage, 614 pounds of beets, and 68 pounds of carrots were grown upon this small tract and sold in near-by markets. Many other vegetables were equally as prolific. Some vegetables grew without irrigation, but the few that matured were practically unmarketable.

POTATOES.

Of the many crops advocated for the semiarid country probably those which are planted in widely separated rows and admit intertillage will be as profitable as any. Of this class of crops potatoes will undoubtedly rank first in a great many districts, although, at lower elevations, some varieties of corn, sorghum, and the nonsaccharines do very well. It has been noticed on the Cheyenne farm that when other crops were suffering for want of water the potato plats, which had received repeated cultivations, were in a fair condition, and the soil contained much moisture. Especially was this true of the plats planted in 54-inch rows. Another condition favoring potatoes as a dry-farmed product is that of superior quality over those irrigated. They are much sought in the markets, and usually bring a better price than irrigated potatoes, which tends to offset the returns of the smaller yield.

The methods used in the production of potatoes on the Cheyenne farm were not unlike those of any successful practical farmer. Labor-saving devices were used wherever possible and much time saved thereby. The seed was generally changed each year and only the best strain of the variety sought was planted. In order to determine which variety would be the most profitable several kinds were tried, and after careful selection the varieties reduced themselves to Early Ohio, Rose Seedling, Strawberry, and Pearl. At present the Early Ohio and Strawberry are being planted, with the former as the favorite. This variety produces as well as any of the others, usually grows to larger sizes, and is generally more acceptable for table use. Neither the large merchantable potatoes nor the very small sizes were used as seed, but an intermediate size was selected.

In order to eliminate as much as possible the disease commonly known as scab, the potatoes were dipped in various standard antiseptic solutions, viz, copper sulphate, formalin, and bichlorid of mercury, which are alleged preventives, but as yet the desired effect has not been obtained on the Cheyenne farm. This disease, which makes the potatoes more unsightly than unpalatable, appears to vary in its intensity with the condition of the soil, probably due to different lime content, for it is not unusual to find spots in a single plat where the potatoes are practically free from scab surrounded by potatoes badly infected. Each year a portion of several plats has been planted with undipped seed, but no great difference was observed in the results. In the selection of seed care is taken to have the potatoes free from premature sprouts. Especially is this true where the seed is to be dipped. Upon receipt of seed potatoes from a distant farmer, which were in an advanced stage of premature sprouting, they were immediately dipped in a solution of bichlorid of mercury and 4 acres of plat 5 were planted with them in the spring of 1906. Without decaying, the seed remained in the ground without life and but few plants grew to maturity.

After dipping and drying, the potatoes were cut with a machine in such a manner that each piece contained from one to four eyes, the blossom end being removed and unused. The seed was allowed to dry again to prevent decay and loss of moisture while sprouting in the ground. The planting was done with a two-horse planter, which very accurately placed one seed in each hill about 4 or 5 inches below the surface. The plats were then cultivated with a spike-tooth harrow, which insured an even covering for the seed and established a soil mulch. The first two or three cultivations given the plants after their appearance through the soil were performed with a spike-tooth harrow having the teeth lying quite flat to prevent the tearing away of the small plants. This was drawn across the plats at right angles to the rows. The preparation of the plats and further cultivation after planting is shown by the following log, which gives a complete history of all potatoes grown on the Cheyenne farm from 1906 to 1908, inclusive.

SEASON OF 1906.

Plats 7 and 8.—Each one-eighth acre; continuously cropped; dry farmed. Steam plowed to a depth of 6 inches and double disked May 1, 1905; harrowed May 16; cross plowed to a depth of 8 inches, one-half of each plat subsoiled, and all harrowed with a spike-tooth June 20; harrowed with a spike-tooth May 14, 1906. Planted with Early Ohio potatoes May 16, in rows 42 inches apart, with the seed 17 inches apart in the rows; harrowed June 19 with a spring-tooth; cultivated June 28; hoed July 10; cultivated July 12; plat 7 cultivated in ridges and plat 8 flat; harvested October 8; average yield, 77 bushels per acre for the two plats.

Plats 17 and 18.—One acre each; summer fallowed. Steam plowed to a depth of 6 inches and double disked May 1, 1905; harrowed with a spring-tooth May 18; har-

rowed with a spike-tooth June 9; cross plowed to a depth of 8 inches, one-half of each plat subsoiled, and all harrowed with a spike-tooth June 15; harrowed with a spring-tooth May 12, 1906. Planted to Early Ohio potatoes May 18, in rows 42 inches apart and 17 inches apart in the rows; harrowed with a spike-tooth June 19; cultivated June 28; hoed July 10; cultivated July 12; harvested October 9; average yield, 89.8 bushels per acre for the two plats.

Plats 27 and 28.—One-half acre each; summer fallowed. Received the same treatment as plats 17 and 18; planted to Pearl potatoes May 18, in rows 54 inches apart, 11 inches apart in the rows, plat 27 being cultivated in ridges and plat 28 receiving flat culture; harvested October 10; average yield for the two plats, 53.2 bushels per acre.

Plats 38 and 39.—One-half acre each; continuously cropped and winter irrigated. Plowed August 17, 1905; double disked August 20; cross plowed to depths of 4, 6, and 8 inches August 25; one-fourth subsoiled; double disked August 27; harrowed with a spike-tooth August 28; harrowed with a spring-tooth April 19, 1906, and with a spike-tooth April 20; received water to a depth of 18 inches in August, 1905; planted to Pearl potatoes May 19, 1906, in rows 36 inches apart and 17 inches apart in the rows; cultivated July 3 and July 12, and hoed July 12; harvested October 11; average yield for the two plats, 82.5 bushels per acre.

Plats 45 and 46.—One-half acre each; continuously cropped and winter irrigated. Plowed to a depth of 4 inches August 16, 1905; double disked August 20; cross plowed to depths of 4, 6, and 8 inches, and one-fourth subsoiled April 16; harrowed with a spike-tooth April 20; irrigated in August and October, 1905, receiving 18 inches of water at each irrigation; planted to Early Ohio potatoes, in rows 30 inches apart and 22 inches apart in the rows, May 19; cultivated July 3 and 12; hoed July 12; harvested October 11; average yield for the two plats, 82.5 bushels per acre.

Plat 51.—Fifteen acres, continuously cropped and winter irrigated. Plowed to a depth of 4 inches October 1, 1905; double disked April 18, 1906; harrowed with spike-tooth April 21; plowed to a depth of 8 inches May 1; harrowed with a spike-tooth May 7; planted to Early Ohio, Rose Seedling, Pearl, and Strawberry potatoes May 21–26, in rows 36 inches apart and 22 inches apart in the rows; cultivated with pulverizing harrow May 22; harrowed with spike-tooth June 1; harvested October 13, practically no crop on 4 acres, seed probably killed by treatment for scab. The yield was about 80 bushels per acre on the remaining 11 acres.

Season of 1907.

Plat No. 3.—One acre, continuously cropped and summer irrigated, in oats and alfalfa in 1906; plowed to a depth of 8 inches and harrowed with spike-tooth March 6, 1907; double disked and harrowed with a spike-tooth March 19; planted to Strawberry and Pearl potatoes May 22 in rows 36 inches apart and 17 inches apart in the rows; irrigated July 18 to a depth of 2.9 inches, and August 16 to a depth of 3.5 inches; harrowed with a spike-tooth May 22; cultivated June 26, July 13 and 20; hoed July 20; cultivated August 9 and 19; harvested October 7, the yield being 101.5 bushels per acre.

Plat No. 8.—One acre, continuously cropped and dry farmed; in peas, wheat, and oats in 1906; received same treatment as Plat No. 3, except that it was not irrigated. The yield was 51.5 bushels per acre.

Plat No. 13.—Three-fourths acre; summer fallowed; no crop in 1906; cultivated with pulverizing harrow March 29, 1907; planted to Strawberry and Pearl potatoes May 23, in rows 36 inches apart and 20 inches apart in the rows; harrowed with spike-tooth May 24; cultivated May 26, July 13 and 20; harvested October 9, yielding 91 bushels per acre.

Plat No. 14.—Three-fourths acre; summer fallowed; no crops in 1906; received the same treatment as plat 13, except that the potatoes were planted in rows 54 inches apart and 20 inches apart in the rows. The yield was 86.2 bushels per acre.

Plat No. 24.—Three and seven-eighths acres; continuously cropped; in wheat, oats, corn, and potatoes in 1906; winter irrigated in March, 1907, to a depth of 4 feet; plowed to a depth of 8 inches May 8; cultivated with pulverizing harrow May 10; planted to Early Ohio potatoes May 27 in rows 36 inches apart and 20 inches apart in the rows; harrowed with spike-tooth May 30; cultivated June 27, July 16 and 23, and August 10; harvested October 6, the yield being 69.3 bushels per acre. The crop was severely injured by hail.

SEASON OF 1908.

Plat No. 1.—One and two-hundredths acres; continuously cropped; summer irrigated; in alfalfa and weeds in 1906; plowed to a depth of 8 inches May 13; harrowed with spike-tooth May 15; planted to Early Ohio and Strawberry potatoes May 21, in rows 36 inches apart and 18 inches apart in the rows; irrigated June 27 to a depth of 3.48 inches, on July 30 to a depth of 2.1 inches, and on August 17 to a depth of 3.69 inches; harrowed with a spike-tooth June 4 and 11; cultivated June 24, July 9 and 16; hoed July 27; cultivated August 3; hoed August 12; harvested October 3, the yield being 120.9 bushels per acre, 62 per cent of the yield being merchantable. The crop was injured by two hailstorms.

Plat No. 10.—Ninety-nine hundredths acre; continuously cropped and dry farmed; received the same treatment as plat No. 1, except that it received no irrigation and received flat cultivation; harvested October 4, the yield being 94.3 bushels per acre, only 55 per cent of which was merchantable; the crop was injured by two hailstorms.

Plat No. 15.—One and fourteen-hundredths acres; summer fallowed; no crop in 1907; plowed to a depth of 8 inches May 12, 1908; harrowed with a spike-tooth May 13; planted to Early Ohio and Strawberry potatoes May 22 in rows 36 inches apart and 18 inches apart in the rows; harrowed with a spike-tooth June 4 and 11; cultivated June 24, July 9 and 27; hoed August 15 and September 4; received flat cultivation; harvested September 30, yielding 109.6 bushels per acre, 57 per cent of which was merchantable; the crop was injured by two hailstorms.

Plat No. 16.—One and eighteen-hundredths acres; summer fallowed; received the same treatment as Plat No. 15, except that the rows were 54 inches apart. The yield was 84.7 bushels per acre, 51 per cent of which was merchantable; the crop was injured by two hailstorms.

Plat No. 20.—Five acres; continuously cropped; in durum wheat in 1907; winter irrigated on October 10, 1907, to a depth of 42 inches, and on March 18, 1908, to a depth of 18 inches; plowed to a depth of 8 inches May 1; harrowed with a spike-tooth May 2; planted to Early Ohio, Pearl, and Strawberry potatoes May 28, in rows 38 inches apart and 17 inches apart in the rows; harrowed with a spike-tooth June 4 and 9; cultivated June 25, July 8 and 15; harrowed with a spike-tooth July 28; cultivated August 6 and 12; received flat cultivation; harvested October 9, yielding 86.3 bushels per acre, 54 per cent of which was merchantable; the crop was injured by two hailstorms.

Averaging the yields of the different plats of potatoes planted at varying distances in 1906, 1907, and 1908, it is found that the land cropped each year which received no artificial application of water yielded 74.3 bushels per acre; that continuously cropped, but irrigated in winter, yielded 80.1 bushels per acre; that summer fallowed yielded 85.7 bushels per acre, and the land continuously cropped, but summer irrigated when necessary, yielded 111.2 bushels per acre. These yields would probably have been increased 20 to 30 per cent had not the potato vines been partially destroyed each year by hail

at the critical periods of growth of the tubers. Ordinarily land winter irrigated should produce a heavier crop than the above, but each year the hailstorms seemed to concentrate over the south farm and do more damage there than on the north farm. Under conditions which are more nearly normal about the same yield would be expected from a winter-irrigated tract as from one summer fallowed where the precipitation has been normal or a little above normal. In years of minimum rainfall, however, the winter-irrigated tract is assured a crop by having stored in the subsoil sufficient moisture to grow and mature a crop each season, more particularly a cultivated crop.

The geographical location is responsible for a short growing season, but crops grow remarkably fast and mature, provided there is a sufficient moisture supply. It is interesting to note that in 1908, twenty-one days after planting the potatoes, the vines were first exposed, sixty-four days after planting they were in bloom, and in eighty-two days the potatoes were large enough to use. The irrigated potatoes, notwithstanding the severe storms, did remarkably well, producing 121 bushels to the acre. The vines were very strong and revived much more readily from the effects of the hail than did any of the others. Upon sacking for market it was found that 62 per cent of the irrigated potatoes on plat 1 were merchantable, while on summer-fallowed plat 16, where the rows were 54 inches apart and large sizes might be expected, only 51 per cent were merchantable.

In dry farming there seems to be a limiting distance between the rows of potatoes, which influences the yield to a certain extent. At Cheyenne potatoes have been planted in rows 36, 42, and 54 inches apart to determine by experience the proper distance of planting. In the 54-inch rows the hills were 11 inches apart, while in the others they were 17 inches apart. There is a distinct advantage in having the rows far enough apart to cultivate late in the season without interfering with or destroying the plants. There is also a greater area from which the plant may draw moisture, but there is a certain distance between rows that is exceeded only to the disadvantage of a reduced yield. This is true also if the distance is reduced, and the best results have been obtained in the 42-inch rows. A more careful investigation is now being made, and 46 inches is the distance assumed to produce the greatest yields. No results are yet at hand to verify the value of this practice.

WHEAT.

Durum wheat has proven a valuable addition to the drought-resistant crops of the semiarid plains. This wheat was introduced by the U. S. Department of Agriculture in 1899 to 1902. In 1906

20,000,000 bushels of durum wheat were exported to Europe, while in 1907 the total yield in the United States was 45,000,000 bushels. This was probably somewhat increased in 1908. Each year durum wheat has been grown on the Cheyenne farm, yielding as high as 27.4 bushels, by weight, per acre on summer-fallowed land. It is a heavy, flinty grain and usually runs over weight. On the Cheyenne farm it was found to withstand the hail exceptionally well on account of the protection afforded by the beards.

Defiance wheat has proven successful at this altitude and withstands hail remarkably well. This wheat has shown up splendidly on the irrigated plats, reaching a maximum yield of 30.9 bushels per acre.

Silver King winter wheat has winterkilled each season to such an extent that it has been abandoned.

Turkey Red winter wheat is undoubtedly the best winter wheat for this district, but it requires moisture at planting to develop a sufficiently sturdy plant to withstand the winter.

The details of the treatment of the plats planted to wheat and the yields are given in the following log:

SEASON OF 1906.

Plat No. 2.—One-half acre; continuously cropped and summer irrigated. Steam-plowed to a depth of 6 inches May 1, 1905; harrowed with a spring-tooth June 7; cross plowed to a depth of 8 inches June 14, and one-half subsoiled and all harrowed with a spike-tooth; harrowed with spike-tooth August 22; planted to Defiance wheat April 11, 1906, in rows 8 inches apart, 44 pounds of seed to the acre; irrigated to a depth of 3 inches on July 10 and 3 inches July 21; no cultivation during growing season; harvested August 17, the yield being 30.9 bushels per acre, of 60 pounds per bushel.

Plat No. 3.—One-half acre; continuously cropped and summer irrigated; intertilled; deep cultivation. Received the same treatment as Plat No. 1, except that the rows were 16 inches apart; intertilled May 28; harvested August 17, the yield being 22.57 bushels per acre. Some grain was destroyed by intertillage, because of a lack of proper implements.

Plat No. 4.—One-half acre; shallow cultivation; received the same treatment as Plat No. 3, the yield being 23.33 bushels per acre.

Plat No. 12.—One acre; summer fallowed. Seeded to durum wheat April 13, 1906, in rows 8 inches apart; 44 pounds of seed to the acre; no irrigation; received the same treatment as Plat No. 4, except that it received no cultivation during growing season; harvested August 13, the yield being 27.42 bushels per acre.

Plat No. 13.—One acre; summer fallowed and intertilled; deep cultivation. Received the same treatment as Plat No. 12, except rows were 16 inches apart; intertilled May 29; harvested August 13, and yielded 23.09 bushels per acre.

Plat No. 14.—One acre; intertilled; shallow cultivation; seeded April 14; received the same treatment as Plat No. 13, except shallow cultivation; harvested August 13, and yielded 22.19 bushels per acre.

Plat No. 21.—One-half acre; summer fallowed and intertilled with spring-tooth harrow. No crop in 1905; received same treatment as Plat No. 14, except it was intertilled May 28 and June 20; harvested August 14, the yield being 23.27 bushels per acre.

Plat No. 22.—One-half acre; summer fallowed, intertilled with gopher blade. Received the same treatment as Plat No. 21; harvested August 14, yielding 21.60 bushels per acre.

Plat No. 23.—One-half acre; summer fallowed and intertilled with spike-tooth harrow. Received the same treatment as Plat No. 22; harvested August 14, the yield being 22.40 bushels per acre.

Plat No. 24.—One-half acre; summer fallowed and intertilled with sweep attachment. Received the same treatment as Plat No. 23; harvested August 14, the yield being 22.40 bushels per acre.

Plat No. 31.—One-half acre; continuously cropped; winter irrigated; no crop during 1905; plowed to a depth of 4 inches August 17, double disked, August 20; cross plowed to a depth of 4, 6, and 8 inches and one-fourth subsoiled August 25; double disked August 27; harrowed with a spike-tooth August 28; harrowed with a spring-tooth April 19, 1906; harrowed with a spike-tooth April 20; seeded to Defiance wheat April 20 in rows 8 inches apart, 44 pounds of seed per acre; irrigated to a depth of 18 inches in August, 1905; no cultivation during the growing season; harvested August 14, the yield being 22.53 bushels per acre.

Plat No. 32.—One-half acre; continuously cropped and winter irrigated; no crop during 1905; plowed to a depth of 4 inches August 17; double disked August 20, cross plowed to a depth of 4, 6, and 8 inches, and one-fourth subsoiled August 25; double disked and harrowed with a spike-tooth August 27; seeded to Silver King wheat September 15; in rows 8 inches apart, 44 pounds of seed per acre; received the same treatment as Plat No. 31, the yield being 19.83 bushels per acre. The crop was partially winterkilled.

Plat No. 33.—One-half acre; continuously cropped, winter irrigated, and intertilled; preparation of seed bed the same as for Plat No. 31; seeded to Defiance wheat April 20, 1906, in rows 16 inches apart, 44 pounds of seed per acre; intertilled June 22; harvested August 14; yield, 20.83 bushels per acre.

Plat No. 41.—One-half acre; continuously cropped and winter irrigated; no crop growing in 1905; plowed to a depth of 4 inches August 16, 1905; double disked August 20; cross plowed to depths of 4, 6, and 8 inches, and one-fourth subsoiled April 16, 1906; harrowed with a spike-tooth April 18; seeded to Defiance wheat April 20, in rows 8 inches apart, 44 pounds of seed per acre; irrigated to a depth of 18 inches in August, 1905, and 18 inches in October; no cultivation during growing season; harvested August 15, the yield being 23.20 bushels per acre.

Plat No. 42.—One-half acre; continuously cropped, winter irrigated, and intertilled; received same treatment as Plat No. 41, except it was seeded in rows 16 inches apart, and intertilled June 6 and 22; yield, 18.10 bushels per acre.

Plat No. 43.—One-half acre; continuously cropped, winter irrigated, intertilled and deep cultivation; received the same treatment as Plat No. 42, the yield being 16.77 bushels per acre.

Plat No. 44.—One-half acre; received the same treatment as Plat No. 43, except a shallow instead of a deep cultivation, the yield being 20.37 bushels per acre.

Season of 1907.

Plat No. 2.—One acre; continuously cropped and summer irrigated; seeded to Defiance wheat in 1906; plowed to a depth of 8 inches March 5, 1907; harrowed with a spike-tooth, double disked, and cultivated with pulverizing harrow March 18; seeded to durum wheat March 20, in rows 8 inches apart, 32 pounds of seed per acre; partially irrigated; no cultivation during growing season; harvested August 17, the yield being 16 bushels per acre; crop partially damaged by hail.

Plat No. 9.—One acre; continuously cropped and dry farmed; planted to peas, wheat, oats, and alfalfa in 1906; received same treatment as Plat No. 2, except it received no irrigation; yielded 3 bushels per acre, the crop being partially damaged by hail.

Plat No. 11.—One acre; summer fallowed; no crop in 1906; steam plowed to a depth of 6 inches May 1, 1905; double disked and harrowed with spring-tooth, May 18, harrowed with spike-tooth June 9; cross plowed to a depth of 8 inches, subsoiled, and harrowed with spike-tooth, June 15; seeded to Silver King wheat September 24, 1906, in rows 8 inches apart, 32 pounds of seed per acre; no irrigation; harvested August 5, the yield being 7 bushels per acre; crop was partially winterkilled and somewhat damaged by hail.

Plat No. 12.—One acre; summer fallowed and intertilled; received the same treatment as Plat No. 11 except it was intertilled June 7 and 22, the rows being 20 inches apart; yield, 7.5 bushels per acre, the crop being partially winterkilled and damaged by hail.

Plat No. 20.—Five acres; continuously cropped and winter irrigated; in rye, wheat, and potatoes in 1906; irrigated to a depth of 4 feet March 7, 1907; plowed to a depth of 6 inches April 22, 1907; cultivated with pulverizing harrow April 22; seeded to durum wheat April 26 in rows 8 inches apart, 32 pounds of seed per acre; received no cultivation during growing season; harvested August 26, the yield being 10.41 bushels per acre; crop damaged by hail.

On Plat No. 23, seeded to Defiance wheat, Plat No. 30, seeded to durum wheat, and Plat No. 34, seeded to Gauss wheat, the crops were ruined by hail.

Season of 1908.

Plat No. 5.—Contains 0.84 acre; continuously cropped and summer irrigated; in field peas in 1907; plowed to a depth of 8 inches September 9, 1907, and harrowed with a spike-tooth September 11; seeded to Turkey Red wheat September 14, in rows 8 inches apart, 30 pounds of seed per acre; irrigated to a depth of 6 inches September 6, 1907, and 3.25 inches June 27, 1908; no cultivation during growing season; harvested August 11, 1908, the yield being 32.28 bushels per acre.

Plat No. 6.—Contains 0.83 acre; continuously cropped and dry farmed; in field peas in 1907; received the same treatment as Plat No. 5, except it received no irrigation; no crop harvested, as it was winterkilled by drought and freezing.

Plat No. 11.—Contained 1.26 acres; summer fallowed; no crop grown in 1907; double disked and harrowed with spike-tooth September 4, 1907; seeded to Silver King September 5; received the same treatment as Plat No. 6, except 29 pounds of seed was used per acre; harvested August 8, 1908, the yield being 6.40 bushels per acre. This grain was cleaned; 50 per cent worthless before cleaning.

Plat No. 12.—This plat contained 1.22 acres; summer fallowed and intertilled; no crop grown in 1907; received the same treatment as Plat No. 11, except rows were 20 inches apart, and intertilled May 5 and June 12, 1908; harvested August 8, the yield being 13.12 bushels per acre; grain cleaned, 30 per cent worthless before cleaning.

Plat No. 21.—Five acres; continuously cropped and winter irrigated; in barley in 1907; seeded to durum wheat April 18, 1908, in rows 8 inches apart, 30 pounds of seed per acre; irrigated to a depth of 42 inches October 23, 1907, and half irrigated to a depth of 18 inches March 18, 1908; no cultivation during growing season; harvested August 26; yield 14 bushels per acre.

Plat No. 22.—Five acres, continuously cropped and winter irrigated; in oats in 1907; seeded to Defiance wheat April 18, 1908; received the same treatment as Plat No. 21; harvested August 31, the yield being 10.4 bushels per acre.

PEAS.

Canadian field peas have been grown successfully each year at the Cheyenne farm. The yield of seed obtained by threshing should not be taken exclusively as a criterion of the crop, for hailstorms and heavy winds opened up many of the pods, causing a material loss in seed. The vines have generally developed into a large quantity of fodder, more especially on the irrigated land, where they often reach a length of more than 4 feet.

Two adjoining plats, 4 and 7, in 1908 were planted to peas, the conditions being identical with the exception that plat 4 was irrigated. The yield of seed from the irrigated plat was 12 bushels per acre, while the unirrigated plat yielded 4 bushels per acre—a marked increase in favor of the irrigated portion. For lambs and pigs peavines with pods make excellent feed and should invariably be fed in the field without cutting. For a green-manure crop they are exceptionally valuable.

The results of all the experiments with peas are shown in the following log:

Season of 1906.

Plat No. 1.—One-half acre; continuously cropped and dry farmed; no crop in 1905; steam plowed to a depth of 6 inches May 1, 1905; double disked May 1; harrowed with a spring-tooth and spike-tooth May 17; cross plowed to a depth of 8 inches, subsoiled, and harrowed with a spike-tooth June 16; harrowed with a spike-tooth August 22; seeded to Canadian peas April 14, 1906, in rows 8 inches apart, with 90 pounds of seed per acre, no irrigation and no cultivation during the growing season; harvested August 20, the yield being 7 bushels per acre.

Plat No. 11.—One-half acre; summer fallowed; no crop in 1905; steam plowed to a depth of 6 inches and double disked May 1, 1905; harrowed with a spring-tooth May 18; harrowed with a spike-tooth June 9; cross plowed to a depth of 8 inches June 15; half subsoiled, and all harrowed with a spike-tooth; harrowed with spike-tooth September 11; received the same treatment as Plat No. 1; harvested August 21, the yield being 15.83 bushels per acre.

Plat No. 40.—One-half acre; continuously cropped and winter irrigated; no crop grown in 1905; plowed to a depth of 4 inches August 17, 1905; double disked August 20; cross plowed to depths of 4, 6, and 8 inches, and one-fourth subsoiled August 25; double disked August 27; harrowed with a spike-tooth August 28; harrowed with a spring-tooth April 19, 1906; harrowed with a spike-tooth April 20; planted to Canadian peas April 20, in rows 8 inches apart, using 90 pounds of seed per acre; irrigated to a depth of 18 inches in August, 1905; harvested August 22, 1906, the yield being 17.63 bushels per acre.

Plat No. 47.—One-half acre; continuously cropped and winter irrigated; no crop grown in 1905; plowed to a depth of 4 inches August 16, 1905; double disked August 20; cross plowed to depths of 4, 6, and 8 inches, and one-fourth subsoiled April 4, 1906; harrowed with a spike-tooth April 20; received the same treatment as Plat No. 40, except 85 pounds of seed per acre were used, and irrigated in August and October, 1905, to a depth of 18 inches each irrigation; harvested August 23, 1906, the yield being 17.03 bushels per acre.

Plat No. 48.—One-half acre. Received the same treatment as Plat No. 47, except the seed was planted in rows 16 inches apart and intertilled in May and June; the yield was 15.13 bushels per acre; crop was slightly damaged by intertillage implement.

SEASON OF 1907.

Plat No. 5.—One acre; continuously cropped and summer irrigated; in rye in 1906; plowed to a depth of 8 inches and harrowed with a spike-tooth March 5, 1907; double disked and harrowed with a spike-tooth March 19; seeded to Canadian peas April 19, in rows 8 inches apart, using 90 pounds of seed per acre; irrigated to a depth of 3 inches July 16; no cultivation during growing season; harvested August 27, the yield being 10.80 bushels per acre; the crop was considerably damaged by hail.

Plat No. 6.—One acre; continuously cropped and dry farmed; received same treatment as Plat No. 5, except it received no irrigation; the yield was 6.08 bushels per acre; crop was damaged by hail.

Plat No. 17.—Three-fourths acre; summer fallowed; plowed and harrowed, but no crop grown in 1906; seeded to Canadian peas April 10, 1907, in rows 8 inches apart, 90 pounds of seed per acre; harvested August 27, the yield being 9.03 bushels per acre; crop partially damaged by hail.

Plat No. 18.—Three-fourths acre; summer fallowed and intertilled; received same treatment as Plat No. 17, except seed was planted in rows 20 inches apart, using 45 pounds of seed per acre; intertilled June 7 and 22, 1907; the yield was 7.08 bushels per acre; crop partially damaged by hail.

SEASON OF 1908.

Plat No. 4.—Containing 1.01 acres; continuously cropped and summer irrigated; in barley in 1907; plowed to a depth of 8 inches, harrowed with a spike-tooth and cultivated with pulverizing harrow March 13, 1908; seeded to Canadian peas April 2, in rows 8 inches apart, 94 pounds of seed per acre; irrigated to a depth of 3.24 inches July 1; no cultivation during growing season; harvested August 17, 1908, the yield being 12 bushels per acre; irrigation unavoidably late, and crop damaged by hail.

Plat No. 7.—Containing 0.97 acre; continuously cropped and dry farmed; in barley in 1907; received same treatment as Plat No. 4, except it received no irrigation; the yield was 4 bushels per acre; crop partially damaged by hail.

Plat No. 13.—Containing 1.20 acres; summer fallowed; plowed and harrowed, but no crop grown in 1907; received the same treatment as Plat No. 7; harvested August 18, the yield being 7 bushels per acre; crop partially damaged by hail.

Plat No. 14.—Containing 1.16 acres; summer fallowed and intertilled May 20 and June 12; received same treatment as Plat No. 13, except rows were 16 inches apart, and 47 pounds of seed used per acre; harvested August 18, the yield being 6 bushels per acre; crop partially damaged by hail.

BARLEY.

It has not been the purpose of this Office to introduce new plants nor breed drought-resistant seed, for, in demonstrating the use of water on the plains, one good variety of grain has sufficed. Beardless and hull-less barley has been grown exclusively on five different plats each season, and has proven to be a good dry-farmed grain, having yielded as high as 21.8 bushels per acre on summer-fallowed land. It makes nourishing feed when ground and mixed with other feedstuffs to form chop. It is not as sure a crop as rye, but makes a better and stronger hay when cut green. When irrigated at the critical period it has developed remarkably full, heavy berries, weighing 62 pounds per struck bushel. The log of the various plats follows:

SEASON OF 1907.

Plat No. 4.—One acre; continuously cropped; in potatoes in 1906; plowed to a depth of 8 inches and harrowed with a spike-tooth March 5, 1907, double disked and cultivated with pulverizing harrow March 18; seeded to beardless and hull-less barley April 9, in rows 8 inches apart, 34 pounds of seed per acre; partially irrigated July 9; received no cultivation during growing season; harvested August 8, the yield being 10.50 bushels per acre.

Plat No. 7.—Continuously cropped and dry farmed; in peas, oats, wheat, and alfalfa in 1906; received the same treatment as Plat No. 4, except it received no irrigation; yield was 4.75 bushels per acre.

Plat No. 15.—Containing 0.77 acre; summer fallowed; no crop grown in 1906; plowed to a depth of 6 inches and double disked May 1, 1905; harrowed with a spring-tooth May 18 and with a spike-tooth June 9; cultivated to a depth of 8 inches with a pulverizing harrow June 15, subsoiled, and harrowed with a spring-tooth. Received the same treatment as Plat No 7, except 32 pounds of seed per acre were used; harvested August 9, the yield being 5.18 bushels per acre.

Plat No. 16.—Containing 0.77 acre; summer fallowed and intertilled June 7 and 22; received same treatment as Plat No. 15, except rows were 16 inches apart, with 30 pounds of seed per acre, the yield being 4.53 bushels per acre.

Plat No. 21.—Five acres; continuously cropped and winter irrigated; in potatoes in 1906; double disked and harrowed with spring-tooth April 2, 1907; seeded April 16, in rows 16 inches apart, with 32 pounds of seed per acre; irrigated to a depth of 4 feet March 7, 1907; no cultivation during growing season; harvested August 1, the yield being 16.75 bushels per acre.

SEASON OF 1908.

Plat No. 2.—One acre; continuously cropped and summer irrigated; in wheat in 1907; plowed to a depth of 8 inches; cultivated with spike-tooth and pulverizing harrows March 13; seeded to beardless and hull-less barley April 2, in rows 8 inches apart, with 32 pounds of seed per acre; irrigated to a depth of 4.02 inches July 11; no cultivation during growing season; harvested August 10, the yield being 15.20 bushels per acre.

Plat No. 9.—Containing 0.97 acre; continuously cropped and dry farmed; in wheat in 1907; same treatment as Plat No. 2, except it received no irrigation; the yield was 13.14 bushels per acre.

Plat No. 17.—Containing 1.19 acres; summer fallowed and no crop grown in 1907; received same treatment as Plat No. 9, except it was plowed and harrowed during 1907; the yield was 21.85 bushels per acre.

Plat No. 18.—Containing 1.23 acres; summer fallowed and intertilled May 20 and June 12; received same treatment as Plat No. 17, except rows were 16 inches apart, with 16 pounds of seed per acre and intertillage, the yield being 17.89 bushels per acre.

Plat No. 24.—Containing 4.44 acres; continuously cropped and winter irrigated; in potatoes in 1907; irrigated to a depth of 42 inches October 23, 1907, and half irrigated to a depth of 18 inches March 18, 1908; harrowed with a spring-tooth and with a spike-tooth April 17; seeded April 22, in rows 8 inches apart, with 32 pounds of seed per acre; no irrigation during growing season; harvested August 4; yield, 10.81 bushels per acre, the crop being partially destroyed by hail.

RYE.

Rye was grown the first season only. This grain has been grown so broadly for a sufficient length of time and the results have been so conclusive that it was abandoned after the first year. It is prob-

ably as easily grown as any small grain and withstands drought well. Unless the farmer has means of grinding the grain for feed it is well to cut it for hay before the heads fill out. The log of the test follows:

SEASON OF 1906.

Plat No. 9.—One-half acre; continuously cropped and dry farmed; harrowed with a spike-tooth to the depth of 6 inches and double disked May 1, 1905; harrowed with a spring-tooth June 7; cross plowed to a depth of 8 inches, one-half subsoiled, and all harrowed with a spike-tooth June 14; harrowed with a spring-tooth August 22; seeded to fall rye September 15, in rows 8 inches apart, with 56 pounds of seed per acre; received no irrigation and no cultivation during growing season; harvested July 26, 1906; yield, 9.71 bushels per acre, the crop being damaged by wind and hail just before cutting.

Plat No. 10.—One-half acre; received same treatment as Plat No. 9, except it was seeded to spring rye, 60 pounds per acre being used; harvested July 30, the yield being 25.07 bushels per acre.

Plat No. 19.—One acre; summer fallowed; received the same treatment as Plat No. 10, except it was seeded to fall rye September 15, 1905, with 56 pounds of seed per acre; harvested July 27, 1906; yield, 8.77 bushels per acre, the crop being damaged by wind and hail just before cutting.

Plat No. 20.—One acre; received the same treatment as Plat No. 19, except it was seeded to spring rye April 13, with 60 pounds of seed per acre; harvested July 30, the yield being 22.25 bushels per acre.

Plat No. 29.—One-half acre; received same treatment as Plat No. 20, except it was seeded to fall rye September 15, 1905, in rows 16 inches apart, 56 pounds of seed per acre, and intertilled May 28 and June 20, 1906; harvested July 27, the yield being 14.32 bushels per acre.

Plat No. 30.—One-half acre; received the same treatment as Plat No. 29, except seeded to spring rye April 13, 60 pounds of seed per acre; harvested July 30, the yield being 16.85 bushels per acre.

Plat No. 34.—One-half acre; continuously cropped and winter irrigated; no crop grown in 1905; plowed to a depth of 4 inches August 17; double-disked August 20; cross plowed to depths of 4, 6, and 8 inches, and one-fourth subsoiled August 25; double-disked and harrowed with spike-tooth August 27. Seeded September 15, in rows 8 inches apart, with 56 pounds of seed per acre; irrigated to a depth of 18 inches in August, 1905; received no cultivation during growing season; harvested July 27, 1906, the yield being 14.11 bushels per acre.

Plat No. 35.—One-half acre; received the same treatment as Plat No. 34, except seeded to spring variety April 14, with 60 pounds of seed per acre; harvested August 24; yield, 8.07 bushels per acre, the crop being damaged by hail.

ALFALFA AND GRASSES.

Alfalfa planted in 1907 on plats 1 and 10 was destroyed by drought and crowded out by Russian thistle. In 1908, however, a stand was obtained on plats 3 and 8, which had been planted to potatoes the year before and were necessarily in a continual state of cultivation. Both plats received the same treatment, except that plat 3 was irrigated. The seeding was done May 15 with a press drill, 12 pounds of Turkestan seed being sown on each acre with no nurse crop. The soil was quite moist from late snows and a good seed bed was readily

established. July 15 plat 3 was irrigated with 4.8 inches of water, August 31 it received 3 inches of water, and September 22 4.3 inches more. At this date the stand on plat 3 was very dense, but that on plat 8 was much thinner and, of course, much smaller and weaker. In the spring of 1909 both plats looked very well, but the effect of the three irrigations was very pronounced upon plat 3.

Five acres, plat 19, of the winter-irrigated tract was planted in the spring of 1907 to Turkestan alfalfa, sowing 12 pounds of seed per acre without a nurse crop. The roots being of no appreciable length during 1907, the plants suffered for want of moisture, but in 1908 fair yields were obtained. This plat showed quite noticeably the effect of the spring irrigation on the north half, where it yielded 1.68 tons per acre in two cuttings, while the south half yielded but 0.7 ton per acre. The plants will have established themselves and heavier yields are expected during the season of 1909.

Plats 25 to 29, inclusive, were planted to alfalfa in 1907 on land summer fallowed the previous season. The alfalfa on some of these plats is in 20-inch rows and on others in 8-inch rows. These plats received no irrigation, but are disked and cultivated frequently. The stand is scattering and the yields have been very light. Three varieties of seed were furnished for experimental purposes by the Bureau of Plant Industry, of this Department, but none of them has proven entirely successful without irrigation.

Of the dry-farmed grasses and hay crops no doubt the slender wheat-grass and *Bromus inermis* are most successful in this district. Plats 32 and 33 are planted to these grasses, respectively. Both plats were seeded May 1, 1907, upon fallowed land. The two grasses wintered remarkably well considering the exceptional dry winter and spring of 1907 and 1908. The slender wheat-grass was cut early on account of the presence of thistles about to seed, but yielded 2,300 pounds per acre, leaving splendid pasture. The brome-grass yielded 1,620 pounds per acre, with good pasture a few weeks after cutting. The yields will no doubt be greater as the roots penetrate and establish themselves in the soil. Both grasses make good hay, which is relished by all farm animals.

THE NEWCASTLE FARM.

The Newcastle, Wyo., farm is in the SE. ¼ sec. 16, T. 45 N., R. 62 W., about 5½ miles north and west from Newcastle. The farm embraces 65 acres of fertile land, most of which is tillable. Oil Creek bounds it on the north and west, while the Chicago, Burlington and Quincy Railroad passes along the eastern boundary.

The farm was located August 1, 1906, upon an unbroken piece of land which at that time was considered representative of the sur-

rounding country susceptible to general agriculture. The surface of the land was covered with a fairly dense growth of sagebrush and cacti, which required much time and labor to remove. What with the construction of farm buildings, digging a well, building fences, and the preparation of the land for plowing, very little time was given to the planting and production of crops the first year. A small amount of horse feed was produced in 1907, but it was not until 1908 that any considerable crops were grown. The soil is an alluvial clay containing enough sand to make it pulverize readily when dry. The farm has sufficient slope toward the creek to insure good drainage, and alkali is not present in sufficient quantities to be harmful to any crops grown.

CLIMATE AND RAINFALL.

The elevation of the Newcastle farm is about 4,300 feet. The difference in elevation between this and the Cheyenne farm has a marked effect upon the growth of farm products. Fortunately the crops have not suffered at any time from the effects of hail since the establishment of the farm. Meteorological records in the vicinity of Newcastle are very meager, there being no authentic data available previous to the summer of 1906.

The following measurements of the precipitation at the farm were made by this Office:

Precipitation at Newcastle farm, 1907–8, in inches.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1907	[a]1.15	0.70	0.30	0.33	2.69	1.86	1.53	0.92	1.76	Trace	Trace	[a]0.35	11.59
1908	.08	.10	1.24	2.47	2.56	5.21	.94	.87	.94	1.54	0.00	.65	16.60

[a] Records from the volunteer observer for the Weather Bureau in Newcastle.

During the winter low temperatures prevail and snowstorms are not uncommon, although most of the moisture is supplied by spring and summer rains. The rains may or may not assume the proportions of a cloudburst. The violence of the storms influences the run-off and hence, to a great extent, the relation of the precipitation to the moisture content of the soil. The Newcastle farm approaches the 20-inch belt of rainfall of South Dakota. This rainfall is sufficient, if applied at the right time, to mature most farm crops; but it is the uneven distribution and more particularly a meager supply at the critical period which makes farming without irrigation uncertain. In 1908 the rains fell at opportune times and produced most magnificent straw and forage, yet after July 1 no rain fell in sufficient quantities to supply the grain in its last stages of maturity. The result was more or less shriveled berries in all the small grains which were not irrigated.

With a view of demonstrating the feasibility of other power than windmills, it was decided to equip the experiment station at Newcastle, Wyo., with a gasoline engine plant. This was in the spring of 1907.

The geological formation of this district is Cambrian. The shale is of great depth and is impregnated with clay, making it so close as to provide small space for water, and therefore it offers great resistance to underflow. The water plane depression angle is a very acute one and but a small supply can be obtained from any one well. Overlying the shale stratum is an alluvial deposit of clay adobe and loam which precludes the percolation of surface water. The underflow is therefore entirely dependent upon stream flow, and this is limited in the locality of this station, owing to its remoteness from large streams draining a large area. The water level occurs at a depth of from 14 to 15.5 feet, having a varation of 1.5 feet during the summer months.

A well was sunk at a point near Oil Creek and was carried to a depth of 22.5 feet. As the well did not pass through the water-bearing stratum its extent was not determined, though the increasing coarseness of the water-bearing material promised a greater flow at lower depths. The well was curbed with loosely placed rock, so that it was impossible to underpin and sink deeper; consequently a steel casing 4 feet in diameter and 6 feet in length was constructed, having fifty 1-inch holes punched throughout its walls. This casing was made in three segments and bolted together upon the ground. Upon two diametrically opposite sides of the casing were bolted 3-inch by 3-inch angle-iron lugs spaced 6 inches apart, so that a 6-inch by 6-inch timber gallows frame could be securely bolted to the casing for supporting a vertical centrifugal pump. The cost of this casing was $49.50.

Prior to the placing of this casing a test was made to determine the capacity of the well. It was found that a maximum of 2.5 gallons in 5.75 seconds, equivalent to a rate of flow of 26 gallons per minute, was all that could be obtained, while after lowering the well by inserting the casing the flow was 2.5 gallons in 5 seconds, equivalent to a rate of but 30 gallons per minute, a gain of but 15 per cent. These tests were made each time after exhausting the well of its storage capacity, requiring about one and one-fourth hours. Since a constant flow of 100 gallons per minute was considered necessary, and since it was thought that at a still greater depth a large flow might be secured, a 6-inch well casing was driven in the bottom of the dug well. The casing was perforated to a depth of 40 feet by drilling three thousand $\frac{1}{16}$-inch holes equally spaced. The cost of drilling the well was $52.50 for a depth of 35 feet below the bottom of the dug well, this being the lowest bid received for the work. The casing, including a

steel driving shoe, cost $76.05 delivered at Newcastle. Shale was encountered at a depth of 18 feet below the bottom of the dug well, though the drilling was continued 10 feet farther because of the possibility of the shale being only a thin stratum. This proved untrue, however, so the work was discontinued.

A test was now made of the well and the flow was but 13.39 gallons per minute, after one hour's pumping to exhaust the storage capacity of the well, or less than one-half that obtained in the last test before sinking the well to the additional depth. The reason for this was that the water plane had lowered considerably, due to excessively dry summer months, and the lack of replenishment of the water body by stream flow. Under these unfavorable conditions of water supply it was necessary to reduce greatly the area to be irrigated or secure a water supply from Oil Creek, a small stream carrying about 30 second-feet of water during the winter and spring months but going dry during the summer months. A survey was made for a gravity ditch to head up the stream about 1½ miles, but the course being up a canyon, the cost of ditch construction would have been excessive and its permanency doubtful. Consequently it was decided that water should be pumped from the creek to a small reservoir located 200 feet from the source of supply. The difference in elevation between the creek level and the maximum level in the weir box is 27.8 feet.

The plan contemplated pumping from Oil Creek while the water was available and filling the reservoir for a final reserve irrigation at a critical time. The seepage and evaporation losses were made up by a small pump operated by a 3-horsepower gasoline engine. The character of the original plant contemplated, had the water supply from the well been adequate, was of a high class, in which a stationary gasoline engine of 8-horsepower capacity was to operate a single-stage vertical centrifugal pump, but the failure of the water supply made it desirable to construct a plant of a less permanent character. The engine originally purchased for the plant was used elsewhere, and a portable 6-horsepower engine, rented for general farm use, was substituted and installed in such a way that it could easily be transferred from the pumping plant to other parts of the farm. This was accomplished by setting heavy sills 8 by 10 inches in the ground and nailing guide strips for each wheel and a bumping post at the end of the channels so provided. The guides and sills were set after the engine had been accurately lined up and in operation, thus making realignment a simple matter. In order to utilize the full power of the engine when the water supply permitted, and yet pump a small quantity of water efficiently when the flow in the stream was low, two pumps were used, one a 2-inch discharge vertical centrifugal, and the other a 2-inch discharge horizontal centrifugal. Thus a pump could be belted to either side of the engine by means of friction-clutch pulleys.

Figure 7 illustrates in sufficient detail the arrangement of the plant. The gallows frame supporting the vertical pump was constructed upon the shore and floated to position over a sump which had been previously prepared. When in place the pump was set and the entire crib sunk to the bottom of the sump by loading with rock. The horizontal pump, not being submerged as was the vertical pump, required priming before operation, but this is automatically accomplished by starting the vertical pump first, when the housing and piping of the horizontal pump become filled with water and so primed. The system is so arranged that a small pump of the single-acting plunger type may be operated separately or in conjunction with the centrifugal pumps. All three pumps discharge into a single 4-inch pipe line to a weir box and thence to the reservoir.

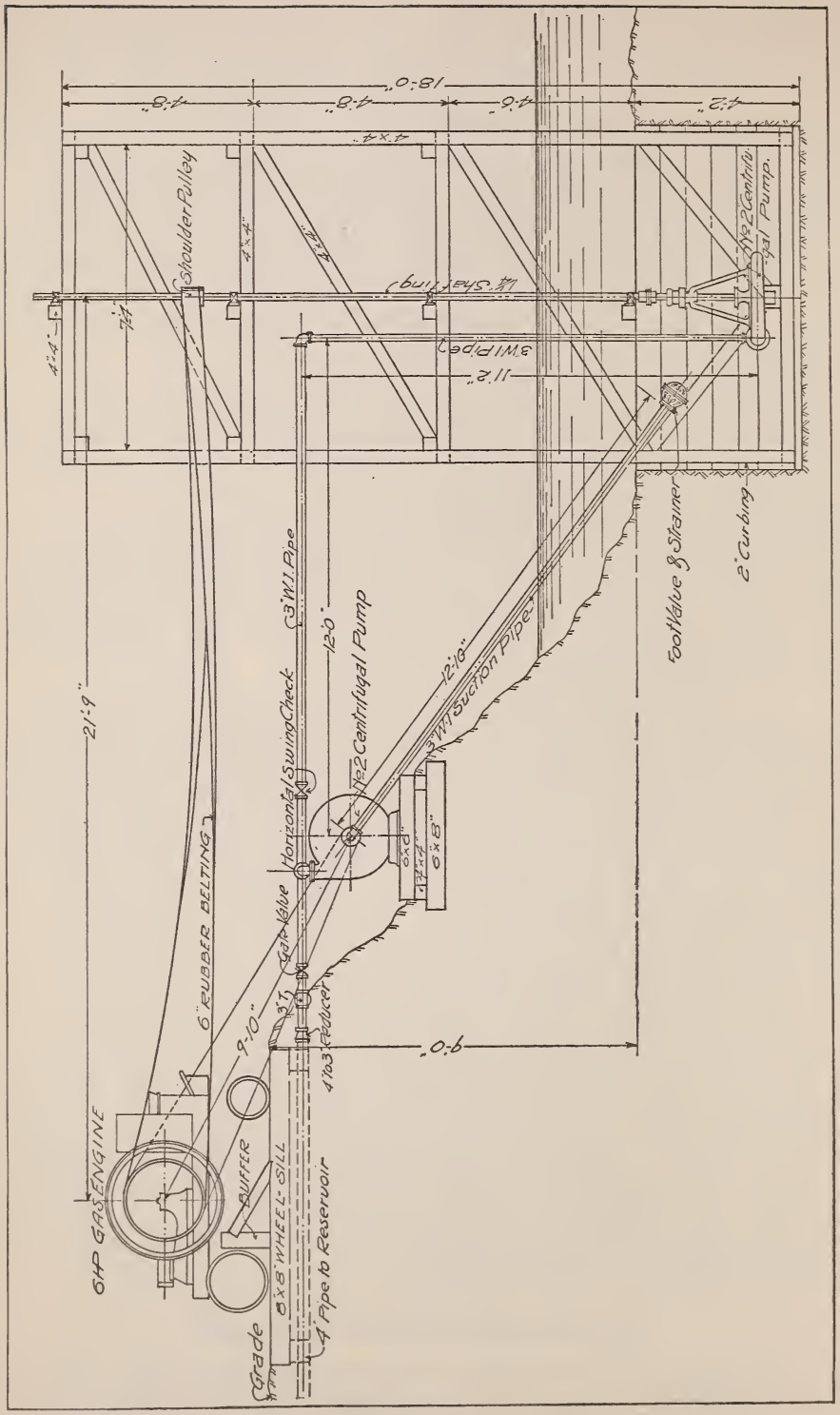
The weir box is fitted with a trapezoidal weir notch and has a register which records continuously the level of the water over the crest of the weir. The weir measures 14 inches at the top, 10 inches at the bottom, and 8 inches in depth.

The total quantity of water discharged under the normal condition of flow in Oil Creek was 180 gallons per minute, exclusive of that supplied by the deep-well pump, which had a capacity of 15 gallons per minute when operating against a 45-foot head. The plant was completed and put in operation May 16, 1908.

The reservoir at this station is similar in construction and size to that at Cheyenne, though not as deep. The material of which it is constructed is an adobe or clayey soil, much more favorable to puddling than that at Cheyenne. The seepage and evaporation losses were excessive at the outset, being about 2 feet per day of twenty-four hours, but this was before the puddling was completed. The season being one of unusual precipitation, 12 inches during the growing season, irrigation was not necessary and experiments were discontinued, to be again taken up later, when different reservoir linings will be tried and the results recorded. The reservoir is supplied with level gauges, similar to those at the Cheyenne station. The reservoir compartments having been cross-sectioned and their capacity determined for various contour intervals, as at Cheyenne, curves were platted so that the quantity of water applied to the various plats could be determined accurately by reading the depths in the reservoir. Water is conveyed through 6-inch galvanized-iron pipes, as at Cheyenne, obviating the necessity of earthen ditches.

PREPARATION OF THE SEED BED.

In the preparation of the land, wherever necessary the plats were double disked immediately after harvest; some were harrowed and some received the plow directly. Slight rains in September and October left the ground in a favorable condition, which made the turning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4'-8"
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Shoulder Pulley
4"x4"
4"x4"
4"x4"

of the soil quite easy. It was then not necessary to follow the plow with the disk in fall plowing. In plowing previously broken ground the plow was held at a depth of about 8 inches, which was as deep as three horses could pull it in this soil. Sod was turned 4 inches deep with a 14-inch walking plow. All seeds were planted with a shoe drill with press wheels attached and were placed under the surface from 2 to 3 inches, or as deep as the drill would permit.

EXPERIMENTS.

Perhaps no other experiments in crop production have shown such remarkable effects from the application of water by irrigation as those carried on at Newcastle during the season of 1908. As stated above, the last effective rain fell July 1. From that time until maturity the grain, having such heavy foliage, presented a large evaporation surface, and being in the process of filling required more moisture than the few inches of surface soil supplied. In consequence wheat suffered and began to burn. The oats had just reached the critical period when water was applied July 24 to both of these crops. The application of water amounted to a depth of from 3 to 4 inches over the surface and was all the grains needed until they were harvested. The yields show the results of this single application of water, which was not needed before this date on account of the natural precipitation, but which, applied at the proper time, saved the crop from being a failure. The following log gives a complete description of the preparation of the seed bed, amount of seed sown per acre, conditions of the growing crops, and yields (see map of Newcastle farm, fig. 8):

Plat 1, Turkestan alfalfa.—Summer fallowed 1907. April 14, 1908, double disked and harrowed; May 5, double disked at right angles to first and harrowed; drilled Turkestan seed, 13 pounds per acre, no nurse crop, ground moist; June 10, growing luxuriantly, ground wet and warm; July 10, harrowed, ground moist under surface; July 25, irrigated a portion of the plat; August 5, cut crop. The irrigated stalks averaged about 22 inches in length, while the unirrigated were slightly shorter. That portion irrigated showed a new growth after cutting, while that unirrigated remained dormant.

Plat 2, Defiance wheat.—Summer fallowed 1907. April 14, 1908, double disked and harrowed; April 15, 33 pounds of seed per acre sowed with press drill, ground moist; April 25, wheat through the soil, ground moist; May 20, growing very slowly, ground wet and cold; June 10, growing very rapidly, ground wet and warm; July 24, crop burning, irrigated a portion of the plat; August 13, the unirrigated area harvested; August 18, the irrigated area harvested; irrigated portion yielded 22.3 bushels per acre. Unirrigated portion yielded 15.9 bushels per acre. As recorded, the unirrigated portion was five days earlier in ripening than the irrigated, due to the extremely dry condition of the soil. The irrigated wheat not only filled out better but the straw also increased in height. The above yields are by weight, 60 pounds being used as the unit. The irrigated wheat was much heavier than the other. Had the water been available a few days earlier and applied before the grain had suffered, no doubt the yield would have been increased still further.

Plat 3, Nebraska White oats.—Summer fallowed 1907. April 14, 1908, double disked and harrowed; April 15, 32 pounds of seed per acre sowed with press drill; April 25, oats appearing through the soil, ground moist; May 20, growing slowly, ground wet and cold; June 10, growing rapidly, ground wet and warm; June 30, growing well, ground dry on surface but moist beneath; July 24, a portion of the plat irrigated; July 30, beginning to ripen; August 10, ripening rapidly; August 27, unirrigated portion harvested; September 3, irrigated portion harvested. Irrigated portion yielded 41.3 bushels per acre. Unirrigated portion yielded 12.3 bushels per acre. Here again the ripening was delayed by the irrigation, but at the same time the berries were filled more completely. With the exception of a slight difference in the height, the oats of one portion of the plat presented practically the same appearance as those of the other. There were as many spikelets to each stalk and as many stalks to each plant, but upon threshing it was impossible to prevent a greater percentage of the berries of the unirrigated oats from being blown through the straw carrier with the chaff. The

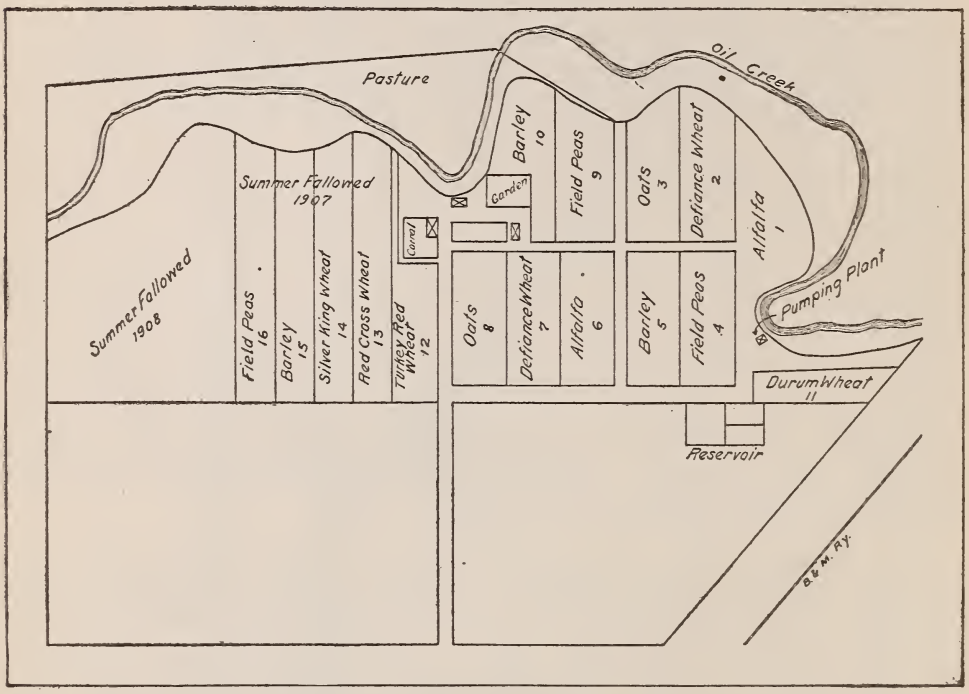

FIG. 8.—Map of Newcastle farm, showing arrangement of plats.

oats were but light hulls with the fleshy portion undeveloped. The unirrigated oats that were delivered by the machine to the sacks weighed but 22 pounds per bushel. The yields given are by weight, with 32 pounds as the unit.

Plat 4, Canadian field peas.—Summer fallowed 1907. April 10, 1908, double disked and harrowed; April 13, 83 pounds of seed per acre sowed with press drill, ground moist; April 25, plants appearing through the soil; May 10 to 20, growing slowly, ground wet and cold; June 10, growing rapidly, ground wet and warm; June 30, growing luxuriantly, ground dry on surface, moist beneath; July 10, plants showing first blossoms, ground moist; July 30, ground very dry. Premature ripening; August 15, crop harvested. Yield 9.67 bushels per acre; length of straw 3 feet. Had there been a supply of water at hand, a small irrigation the latter part of July would probably have increased the yield materially. There was a good yield of straw, however, which would have made excellent pasturage.

Plat 5, Beardless and Hull-less barley.—It was the original intention to irrigate this plat as well as the ones just described, but owing to a limited water supply only a

portion of the first three plats could be irrigated. All the plats were summer fallowed in the preparation of the land the year before, so presented those conditions sought in regular dry-land farming. It is quite probable if these plats are cropped each year the yields will be greatly reduced unless irrigation is practiced. An effort will be made to supply all of these plats with the necessary amount of water to mature the crops during the following seasons. Summer fallowed 1907; April 10, 1908, double disked and harrowed; April 13, 31 pounds of seed per acre sowed with press drill; April 25, plants through the soil, ground moist; May 10 to 20, growing slowly, ground wet and cold; June 10, growing rapidly, ground wet and warm; July 10, beginning to head, ground dry on surface; July 20, beginning to ripen; August 3, harvested, yield 22.7 bushels per acre.

Plat 6, Turkestan alfalfa.—Summer fallowed 1907. April 10, 1908, double disked and harrowed; May 4, harrowed; 13¾ pounds seed per acre sowed with press drill, ground moist; May 14, plants appearing through the soil, ground wet and cold; June 10, growing luxuriantly, ground wet and warm; June 30, harrowed, soil dry on the surface; July 20, harrowed with spike-tooth harrow with the teeth flat and well sharpened, ground moist beneath mulch; August 5, first crop cut, stalks 14 inches high. The yield was fair for the first season, but plants showed the lack of moisture.

Plat 7, Defiance wheat.—Summer fallowed 1907. April 10, 1908, double disked and harrowed; April 13, 32½ pounds of seed per acre sowed with press drill; April 25, plants through the soil, ground moist; May 10, growing slowly, ground wet and cold; June 30, growing rapidly, ground moist and warm; July 10, beginning to head; July 20, ground dry, straw presented the appearance of a bountiful crop; July 30, ripening very rapidly; August 12, harvested, grain light, yield 15.6 bushels per acre; length of straw, 3 feet 2 inches.

Plat 8, Nebraska White oats.—Summer fallowed 1907. April 9, 1908, double disked and harrowed; April 11, 34 pounds of seed per acre sowed with press drill, ground moist; April 19, plants through the soil, ground moist; May 10 to 20, growing slowly, ground wet and cold; June 11, growing rapidly, ground wet and warm; July 1, beginning to head, ground moist and warm; July 30, ripening in spots, due to drought; August 27, harvested, yield 8.7 struck bushels of 22 pounds, or 6 bushels by weight; length of straw, 2 feet. On this plat, as well as on the unirrigated portion of plat 3, the oats were very light in weight, due to nonfilling of the grain; the straw was of good length and spikes plentiful, but the grain could not fill properly for lack of moisture.

Plat 9, Canadian field peas.—This plat was planted to barley in 1907; otherwise the treatment of the land was the same as that of plat 4. The effect of continuous cropping was conspicuously shown in the length of the straw, which was 10 to 12 inches shorter here than on plat 4. No accurate measurement of the yield could be made on account of much seed having been threshed out by a heavy wind after the peas had been cut.

Plat 10, Beardless and Hull-less barley.—This plat was planted in 1907 to Durum wheat, hence is one of the plats continuously cropped. Land plowed in the fall of 1907; April 14, 1908, double disked and harrowed; April 15, 29¼ pounds of seed per acre sowed with press drill, ground moist; April 28, plants appeared through the soil; May 10 to 20, growing slowly, ground wet and cold; June 1, growing rapidly, ground wet and warm; June 30, beginning to head, ground moist and warm; July 20, beginning to ripen, surface of soil dry; August 4, crop harvested, yield 11.6 bushels per acre; length of straw, 3 feet.

Plat 11, Durum wheat.—Summer fallowed 1907. April 17, 1908, double disked and harrowed; April 18, 28 pounds of seed per acre sowed with press drill, ground moist; April 25, plants appearing through the soil; May 10 to 20, growing slowly, ground wet and cold; June 10, growing rapidly, ground wet and warm; July 2, be-

ginning to head, ground moist and warm; July 20, beginning to ripen in spots, ground very dry; August 15, crop harvested, yield 12.3 bushels per acre; length of straw, 4 feet.

Plat 12, Turkey Red wheat.—Wheat grew very luxuriantly at Newcastle. The straw would have led one to estimate the crop at 75 bushels per acre, but, as in other cases, the lack of moisture at the critical period reduced the yield by nonfilling of the grain. August 12, 1907, plowed 8 inches deep, double disked and harrowed; September 25, harrowed; September 28, 27 pounds of seed per acre planted with press drill, ground moist; October 10, plants through the soil, ground moist; December 1, luxuriant stand, ground moist; January 1, 1908, ground very dry; February 1, ground very dry, less than 2 inches of snow to date; March 1, ground dry, but no indication that crop had been winterkilled; April 1, beginning to grow, plants looking fine; June 20, beginning to head, ground wet; July 20, ripening rapidly, ground very dry; July 30, harvested, yield 22.3 bushels per acre; average length of straw, 4 feet 6 inches; berries not filled out properly for lack of moisture at last period of growth.

Plat 13, Red Cross wheat.—This plat was plowed and planted at the same time, under the same conditions, and with the same amount of seed as plat 12. December 1, 1907, there was an even stand over the plat, but after passing through the winter the east end of the plat, which is less protected than the west end, showed a considerable area winterkilled. The grain began to head about the same time as the Turkey Red, and on account of the dry weather in July ripened rapidly, as did the other winter wheats. The crop was harvested July 30 with a splendid stand of straw 4 feet 4 inches long, yielding 20 bushels of grain per acre.

Plat 14, Silver King wheat.—Probably no other wheat on the farm exhibited such magnificent straw and heads as did the Silver King, but the berries were decidedly lacking in quality. Some of the heads were over 7 inches long while the straw often measured 5 feet in height. The precipitation during the early part of the season seemed to be ideal for forage production. This plat was plowed, cultivated, and seeded under the same conditions as the last two described, with the exception of the amount of seed, which was limited to 25 pounds per acre. As in the case of the Red Cross wheat the east end of this plat was winterkilled, which seems to place a value upon the wind-break to the west and north along the creek bank. This wheat experienced the same dry conditions as the others at the end of the season and ripened with them. The yield was 20.5 bushels per acre.

Plat 15, Beardless and Hull-less barley.—Land summer fallowed 1907. April 17, 1908, double disked and harrowed; April 18, 28 pounds of seed per acre sowed with press drill, ground moist; April 25, plants through the soil; May 10 to 20, growing slowly, ground wet and cold; June 1 to 20, growing rapidly, ground wet and warm; July 1, beginning to head, ground moist; July 20, beginning to ripen, ground dry on surface; July 30, ripening rapidly, ground very dry; August 15, harvested, yield 12.3 bushels per acre; length of straw, 3 feet 2 inches.

Plat 16, Canadian field peas.—Land summer fallowed 1907. April 17, 1908, double disked and harrowed; April 18, 88½ pounds of seed per acre planted with press drill, ground moist; April 25, plants through the soil; May 10 to 20, growing slowly, ground wet and cold; June 10 to 20, growing rapidly, ground wet and warm; June 30, beginning to blossom, ground moist; July 10 to 20, ripening fast, ground very dry; August 4, harvested, yield of seed not determined on account of having been partially threshed out by a heavy wind after cutting. A previous determination showed a yield of 1.38 tons of green forage per acre.

Garden.—A small garden was established in which cabbage, tomatoes, carrots, lettuce, onions, cucumbers, turnips, and sweet corn grew to splendid sizes and of excellent quality under irrigation. Calculating the yield from the small amount raised the cabbage produced about 12 tons per acre, while from four rows of 90 feet each tomatoes

yielded over 300 pounds of green fruit, together with an abundance of ripened ones. Rhubarb and small fruits are growing nicely with frequent irrigations, but are too young as yet to yield any returns. Several shade trees of common cottonwood and Carolina poplars were planted in the spring of 1908, the soil having been well irrigated at planting time. These trees grew from 1 to 3 feet the first season, with irrigations August 26 and November 29.

Owing to the small amount of water available little data for comparing the returns from irrigated and from unirrigated plats were secured in 1908, and it would not be advisable to base conclusions on the results of a single season, even if more data had been secured. Irrigated alfalfa made a better growth than that unirrigated. On plats irrigated Defiance wheat yielded 22.3 bushels as compared with 15.9 bushels from the unirrigated portion, an increase of 42.5 per cent. On plat 3, Nebraska White oats yielded 41.3 bushels, while the yield from the unirrigated portion was but 12.3 bushels, the increase being 236 per cent. All of the grains, whether irrigated or not, made a remarkably fine growth of straw, but the lack of water at the time when the heads should have filled resulted in a small yield of light grain. This failure of the grain to fill out is the most conspicuous result of the experiments in 1908.

The years covered by this report have on the whole been years of more than normal precipitation, and at Cheyenne the crops have been injured by hail each season, but even under these adverse conditions the great advantages arising from irrigation are clearly shown. The experiments must be continued for several more seasons before definite conclusions as to cost of irrigation and the profits arising can be reached.

Although the report covers only a single season at Newcastle, the results have been more pronounced than at Cheyenne. The rainfall at Newcastle was far above the normal and produced a remarkable growth of straw with all grain crops, but without irrigation the heads failed to fill, and the crops of grain were small and light. The irrigated grain filled well, and produced good crops. This protection against drought at a critical period of the growth of the crop is the great object of irrigation in the semiarid and humid sections of the country, and its value is seldom illustrated better than at Newcastle in 1908.

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